REMOTE SENSING AND GIS IN THE DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR SUSTAINABLE MANAGEMENT OF THE DRYLANDS OF EASTERN AFRICA: A CASE OF THE KENYAN DRYLANDS

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KEY WORDS: Decision Support System, Geographical Information System, Remote Sensing, Land Use, Vegetation, Land Degradation, Land Use Planning, Environmental Management

ABSTRACT:

Significant proportion of land areas of the countries in the horn of Africa is dryland. The dry lands comprise the areas traversed by the Great East African Rift Valley and are highly susceptible to land degradation due to many factors including natural as well as man-made such as increasing population, over-exploitation of resources and generally being a fragile environment. The Regional Centre for Mapping of Resources for Development (RCMRD) in collaboration with European and African partners undertook a project in three countries of eastern Africa (Ethiopia, Kenya and Tanzania) with an aim of developing a decision support system (DSS) for sustainable development of drylands in the respective countries. In pursuit of this goal, GIS modeling was used to support decision-making on agricultural product development and distribution, natural resource management, environmental rehabilitation, and institutionalisation of indigenous environmental knowledge. The project implemented between November 1997 and May 2001 involved the participation of several institutions in Europe and in Africa. Each partner had specifically defined roles in the study. RCMRD was responsible for GIS development; vegetation assessment, analysis and mapping using aerial photography as well as remote sensing techniques; and application of participatory rural appraisal (PRA). Other tasks included analysis of livestock ranching and environmental management systems in Kenya, organizing field trips in Kenya and collation of remote sensing data for all the partners. In close collaboration with the Centre was the Centre for Biodiversity of the National Museums of Kenya whose responsibilities were the revision of the biological assessment of the study sites in Kenya; data collection on vegetation and fauna in Kenya; analysis of indigenous foods and community sustainability; use of biodiversity products, medicinal plants, indigenous knowledge and practices in environmental management; and contribution in the development of a biodiversity database in collaboration with the other partners. This data was used to develop a DSS for the study with an aim of applying the developed system to other similar areas. This paper presents the methodology and the results of the study and also proposes the way forward.

1. INTRODUCTION

1.1 Rationale for Undertaking this Study

Arid and semi-arid lands have been listed in Agenda 21 among the fragile ecosystems of the world although they are described as being important ecosystems, with unique features and resources. These ecosystems are regional in scope, as they transcend national boundaries. Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Desertification affects about 17% of the world's population, 70% of all drylands amounting to 3.6 billion hectares, and 25% of the total land area of the world (Agenda 21 and World Desertification Atlas, 1997). The most obvious impact of desertification, in addition to widespread poverty, is the degradation of 3.3 billion hectares of the total area of rangeland, constituting 73% of the rangeland with a low potential for human and animal carrying capacity; as well as decline in soil fertility and soil structure on about 47% of the drylands (United Nations Conference on Environment & Development, Rio de Janeiro, Brazil, June 1992).

The priority in combating desertification and effects of droughts should be the implementation of preventive measures for lands that are prone to degradation while designing mechanisms to rehabilitate the severely degraded ones. In combating desertification and drought the approach should be multidisciplinary while calling on the participation of all the stakeholders such as local communities, rural organizations, national Governments, non-governmental organizations and international and regional organizations is essential. Given here below should comprise among the key strategies:

- Strengthening the knowledge base and developing information and monitoring systems for regions prone to desertification and drought, including the economic and social aspects of these ecosystems;
- Combating land degradation through, inter alia, intensified soil conservation, afforestation and reforestation activities;
- Developing and strengthening integrated development programmes for the eradication of poverty and promotion of alternative livelihood systems in areas prone to desertification;
- Developing comprehensive anti-desertification programmes and integrating them into national development plans and national environmental planning;
- Developing comprehensive drought preparedness and drought-relief schemes, such as early warning systems, for drought-prone areas and designing programmes to cope with environmental refugees;
- Encouraging and promoting popular participation and environmental education, focusing on desertification control and management of the effects of droughts.

The global assessments of the status and rate of desertification conducted by the United Nations Environment Programme

(UNEP) in 1977, 1984 and 1991 have revealed insufficient basic knowledge of degradation (desertification) processes (Agenda 21, 1992). The capacity of existing international, regional and national institutions, particularly in developing countries, to generate and exchange relevant information is limited. An integrated and coordinated information and systematic observation system based on appropriate technology and embracing global, regional, national and local levels is essential for understanding the dynamics of desertification and drought processes. It is also important for developing adequate measures to deal with desertification and drought and improving socio-economic conditions.

1.2 The SUNRISE Project Objectives

Several countries of eastern Africa among them Kenya, Ethiopia and Tanzania have been identified as having common interests in managing and developing their arid and semi-arid lands. These countries have certain degrees of land degradation and particularly in the most arid zones along the Great East African Rift Valley. These countries have an obligation to develop their arid land resources while sustaining an ecological balance and conserving the diverse biological resources therein. Combating desertification and land degradation in this sub-region forms the core of environmental programmes of the respective countries. The SUNRISE Project was, therefore, conceived and developed to look at some of these issues in the three countries of the eastern Africa (Kenya, Ethiopia and Tanzania) sub-region. The main long tern objective of the Project was to stop land degradation in the dry lands by organizing, strengthening and implementing the achievements of a set of previous European Union funded projects within the sub-region. The results from this Project, which are GIS based, are expected for use by planning authorities to define strategies for sustainable development and environmental rehabilitation.

In the context of the SUNRISE Project, the primary goal of the GIS component is to assist local planning authorities to define and implement strategies for sustainable development and environmental rehabilitation in semi- arid areas. The secondary goal is to use the GIS to bridge the gap between the top-down and bottom-up planning approaches. In pursuit of these goals, the GIS models would be used specifically to support making decisions on several choices among them development and distribution of agricultural products, natural resource management, environmental conservation and rehabilitation methods, and institutionalisation of indigenous environmental knowledge.

The implementation of the project called for collaboration between several institutions both in eastern Africa and in Europe. The participating institutions were the Universities of Trieste and Florence (in Italy), the University of Madrid (Spain), the University of Wageningen (Netherlands), University of Wales (UK), Addis Ababa University (Ethiopia), Mekele University (Ethiopia), University of Dar-Es-Salaam (Tanzania), National Museums of Kenya, the International Institute for Environment and Development (UK), and the Regional Centre for Mapping of Resources for Development (RCMRD), (Kenya).

1.3 The Kenyan Study Site

The original study area for Kenya included the catchment areas of Lakes Naivasha, Elementeita and Nakuru based on the Monitoring Lakes in Kenya Project implemented in Kenya in 1992-1995. The three lake catchments are enclosed by an area of, approximately, 90 x 90 km, located between latitudes 0°09'S to 0°55'S, and longitudes 35°50'E to 36°42'E. This area is about 70km northwest of Nairobi. The elevation above sea level of these lakes ranges from 1,884m (L. Naivasha) to 1,758m (L. Nakuru). This section of the Rift Valley is bounded by the Aberdare Ranges to the east and the Mau Escarpment to the west. The Rift Valley width in this region is approximately 60km. This study area was, however, modified as dictated by data availability and now covers Nakuru District as shown in Figure 1. The SUNRISE Project did not have sufficient facilities to completely generate new data for a good number of activities hence there was heavy reliance on the usage of secondary data without a compromise on the quality or coverage of this information.

The study area in Kenya falls partly in the semi-arid zone of the Rift Valley. It is in an area of increased land use/land cover changes due to the presence of high agricultural activity in the area. The area is rich in biodiversity that is being threatened with depletion due to the great influence from the development activities in the area. It falls within the stated study objective requirements. This area was also chosen due to the perceived availability of the previous information from the past project. Previous work in the area assembled various environmental databases aimed at simulating lake level changes, on a monthly basis for the development of a Hydrological Model (Studdard et al., 1995). The model largely gave a detailed analysis of the lake basin to determine which physical, meteorological and geographic parameters influence different hydrological regimes. The model was designed to operate on spatial data units, giving it the ability to simulate changes in the spatial data sets such as changes in land use within the catchment. This allows it to be very much more useful for water resource modelling than a simple lake water balance model, whilst avoiding the complexity of a fully distributed model (i.e. one which attempts to describe the complete hydrological system).

2. METHODOLOGY

The methodology developed for sustainable development of arid lands in eastern Africa calls for integration of various environmental and natural resources information into a GIS to model various management alternative scenarios. Of interest would be information on terrain models (DTM), vegetation, climate, soils, land use, geomorphology, slopes and hydrology among others. Such information would be useful in estimating the rate of soil erosion as well as determining areas susceptible to such vices. The project also focussed on if or how GIS and Remote Sensing techniques can support planning activities aimed at rehabilitating degraded environments. The project aimed at:

- Developing an environmental assessment methodology for political and socio-economic decision making at different administrative levels regarding resources allocation.
- Use geological, archaeological and hydroclimatological field data in combination with socio-economic information to analyse soil erosion and other degradation processes in the study areas.
- Integrate remote sensing data with several other data types into a GIS to develop various models for decision-making.

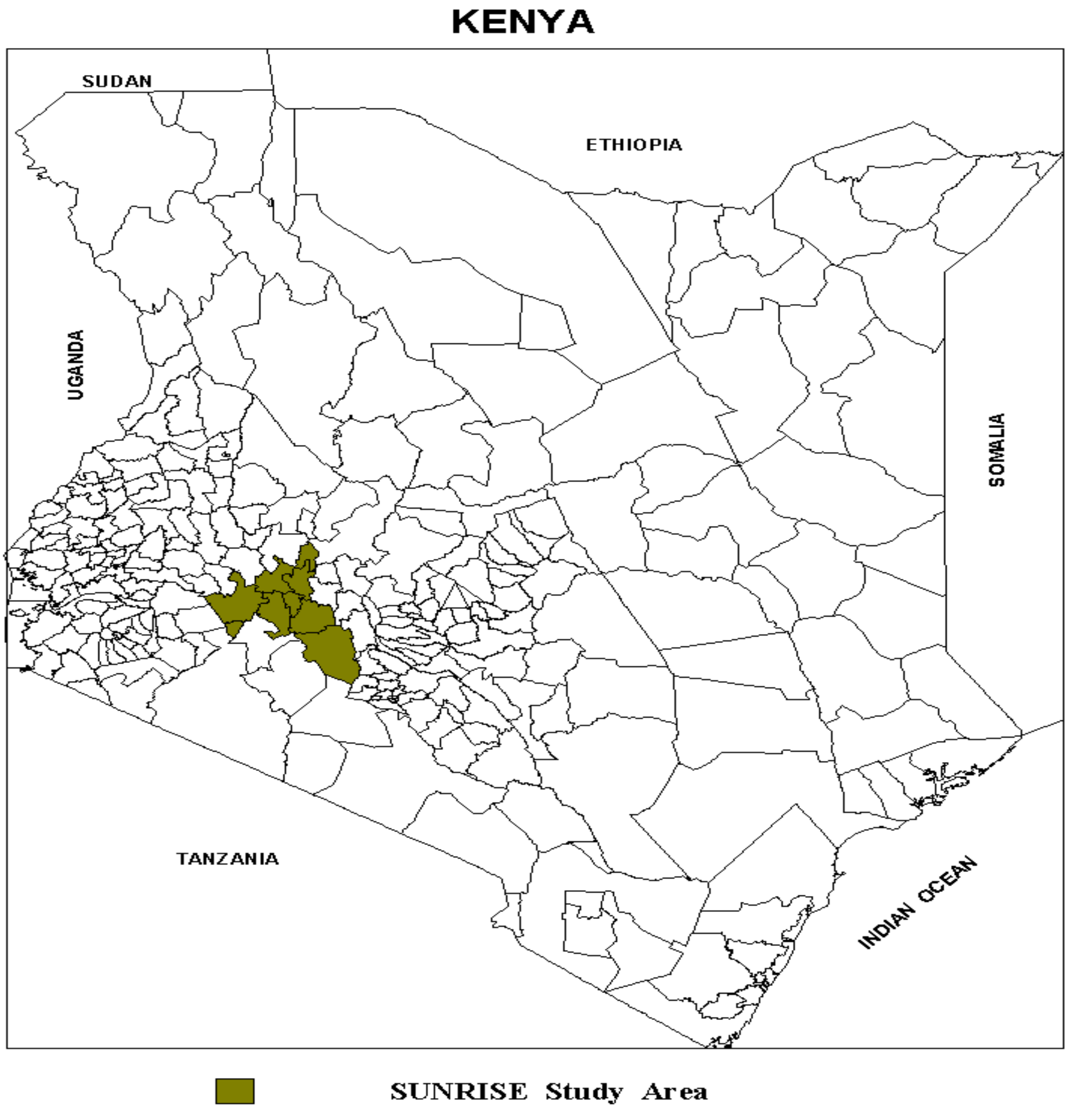

Figure 1. The project study area

In this study, the rural system is perceived as a geo-ecosystem, a unit, in which the human interface through the influence of cultural heritage and knowledge accumulated over a long period of time strongly interact with and influence environmental processes. With regard to this, the research study included indigenous knowledge by understanding, explaining and evaluating the knowledge in scientific terms.

While carrying out the study, an interactive procedure based on successive approximations of landscape classification, scientific modelling using geographical information system (GIS) and consultation with the local residents of the study area as well as with local organisation (administration and NGOs) was developed. Besides the classical scientific investigations techniques (applied by the research team), the Participatory Rural Appraisals (PRA) for problem diagnosis and for joint feedback evaluations and discussions of results by farmers (local residents) and researchers for identification of key constraints, inefficiencies, room for improvement, etc was applied.

During the study several field studies were conducted in all the study sites. The Kenyan team carried out a fieldwork around the catchment area of Lake Nakuru and the findings of that work are form the basis of discussion in this paper.

2.1 GIS Structure and Design

The GIS model comprises the GIS data that is linked to the GIS data inputting, data processing and data outputting components. The data manipulation by the operator(s) is then linked with the various data users/consumers. The Operator(s) is (are) the GIS expert(s) who transform(s) the specific user requirements into GIS analysis questions and indigenous environmental knowledge into operational GIS data. The consumers, on the other hand, include individuals who make the day-to-day decisions on what to produce, how to do it, how to distribute, which areas to be conserved and how to do it. In attempt to implement a bottom up approach, all these players need to be incorporated into the GIS implementation, and their knowledge and needs ought to be incorporated in the GIS operations. The diagram showing the GIS structure and design is shown in Appendix A.

2.2 GIS User Requirement Analysis

From the Project objectives pint of view, the GIS model answers or helps to make decisions along a set of queries some of which include showing, the spatial distribution of different natural resources in the area; spatial distribution of some socio-economic facilities and services; land capability and suitability analysis; land allocation; determination of carrying capacity; land improvement measures; and environmental quality monitoring.

2.3 Data Development (Sources and Types)

In order to develop a system that can be used to locate, assess, allocate and conserve natural and human produced resources there is need to have information about where they are, what quantities are available, what alternatives exist, the competing uses/users, etc.

The identified data for this project is obtained from four major sources namely:

- Published maps - topographic, geological vegetation, soils, agro-ecological,
- Remotely sensed data - satellite imagery
- Government publications - census reports, economic reviews, statistical abstracts, development plans, annual district reports, weather reports, etc.
- Primary field data - field data collection using global position systems (GPS) to update point feature files (new facility/service centres), "ground truthing", data for image classification, etc.

One of the primary data collection method applied was fieldwork carried out at two levels of data collection. The first level involved general observation by the research team whereas the second level involved in-depth interview with individual farmers who were selected randomly and without any prior arrangement. The interviews that were carried out verbally were on question-answer basis. The analysis adopted ensured simple environmental and land use assessment of the catchment area but from a scientific point of view.

3. RESULTS

3.1 Fieldwork and Database Development

The fieldwork was carried out at two levels of data collection. The first level involved general observation by the research team whereas the second level involved in-depth interview with individual farmers who were selected randomly and without any prior arrangement. The interviews that were carried out verbally were on question-answer basis. The results have been analyzed on a simple straightforward approach without applying any complicated scientific approaches. They are, therefore, based on simple environmental and land use analyses of the catchment area but from a scientific point of view.

3.2 Spatial Database Assembly

Among the spatial databases assembled:

a) Digitized administrative units assembled for Nakuru District.
b) Digitized topological sheets covering the study area. The databases digitized include communication network, roads and railways, drainage (rivers, lakes, water points), land cover types, and contours at vertical interval of 20 m.
c) Population and population density maps.
d) Agro-ecological zoning map of Nakuru District.
   The agro-ecological zoning was done by the Ministry of Agriculture of the Kenya Government in collaboration with a German Agricultural Team and is based on temperature. The zones are given as Tropical Alphine, Upper Highland, Lower Highland, Upper Midland, Lower Midland and Lowland. The zoning also classifies the district in terms of suitability for agricultural production.
e) Humidity Map, which is given in terms of rainfall reliability with particular reference to the second rains (short rains – October - December).
f) Average annual rainfall map for Nakuru District, which maps the rainfall distribution in Nakuru District.

It is, however, important to note that subsequent combination of these databases for multi-criteria analysis has not yet been performed adequately.

3.3 Fieldwork Report

3.3.1 Farmer's Year of Settlement, Farm Sizes and Farming Types: The majority of the farmers interviewed settled in the area in the mid 1970s, mainly around 1975. This was particularly so in Lare and Gilgil Divisions where, in fact, the farming conditions are poorer, most parts of these divisions being rangelands. From the rangeland management point of view, the two divisions are not suitable for sedentary agriculture. Mauche Division comprises a high potential agricultural area the settlements there having been curved out of the Mau and Chepalungu Forests. The settlements there are more recent, most of the area seems to have been settled in the 1990s.

The long-term implications of the changes in land use systems, from rangelands to agricultural lands and the conversion of forestland to agriculture are subject of scientific research. However, environmental degradation is noticeable and even one of the interviewees revealed that crop yields have declined over the year.

Although there exists some medium scale farms growing principally wheat and some barley, most of the farmers interviewed were small-scale farmers with land sizes being about one hectare or less. All the farmers interviewed (quite representative of the area) practised mixed farming principally for subsistence although with commercial aspects.

3.3.2 Types of crops grown, yields realized and farm inputs applied: The main crops grown are maize and beans, usually intercropped. Other food crops grown include sorghum, and potatoes horticultural crops such as oranges, kales, tomatoes and bananas. One of the farmers was growing pyrethrum as a cash crop. The best yields achievable (for maize and beans) are 10 bags per acre for maize and 3 bags per acre for beans. From observations, the yields increase with increase in potentiality of the land and vice versa. Most farmers achieve less than 10 bags of maize per acre. From the interviews it is apparent that crop failures are common, mainly as a result of droughts.

There is significant application of modern farming techniques. From the interviews, 80% of the farmers use organic manure whereas 60% were using inorganic fertilizers. Farmers also appreciated the use of certified seeds.

3.3.3 Main problems experienced by the farmers in this area: The leading problems experienced by all the farmers are lack of water and frequent droughts. Pests and wildlife were also reported as big problems because they destroy crops or some wild animals also kill livestock. Among the pests reported were wild birds such as guinea fowl. Wildlife was a bigger menace for those settled near the Lake Nakuru National Park. Among the wild animals reported as causing problems were baboons, monkeys, gorillas and wildebeests, which destroy crops.

Other problems reported were lack of credit facilities hindering farm development, lack of extension services, poor communication (due to poor roads, particularly during the rainy season), lack of electricity and occurrence of diseases (attacking people, livestock and crops).

3.3.4 Environmental conservation practices carried out in the area, and the trees commonly planted: As a means of curbing environmental degradation, several conservation measures are practised by farmers in the area. Among the practices were terracing or terracing combined with planting of Napier grass. Both the practices are aimed at reducing run off hence reducing soil erosion by water. Besides acting as a soil conservation agent, Napier grass is also used as livestock feed. Among other conservation measures were general tree planting. The main Agroforestry trees either noticed or reported was Grevillea robusta found in about 80% of the farms visited. Other agroforestry trees included Acacia species, Casuarina, Luceana and Cesbania. Agroforestry practice serves several purposes – holding the soils together to reduce erosion, adds crop nutrients to soil (e.g. Nitrogen Fixing) hence increasing soil fertility, parts of the trees are used as animal feeds (particularly the leguminous ones), the trees provide polls for construction as well as being used as sources of energy for firewood. Besides the agroforestry trees listed above, other trees included Jacaranda (used for ornamental purposes as well as fire wood) Croton Megalocupus, Euphorbia sp., Cypress and Pinus. The main purposes of tree planting are several, among them prevention of soil erosion, as a source of firewood (energy), timber, fencing, plot demarcation, and for ornamental purposes.

3.3.5 Livestock production; type of livestock kept, livestock products and the grazing systems: The main types of animals kept are cattle, kept by about 80% of the respondents. About 60% of the farmers also kept poultry (chicken). Other animals kept included goats and sheep. Cattle appeared to be kept for milk hence providing significant amounts of income whereas most other animals seemed to be kept for domestic purposes. Chicken also appeared to be providing some eggs for sale hence contributing to family income. The animals kept could also provide meat, particularly poultry for domestic consumption. About 40% of the farmers practised zero grazing, a similar percentage practising free ranging and 20% tethering the animals.

3.3.6 Socio-economic information: The socio-economic aspects of this study mainly looked at family size, access to education, access to health facilities and services, and the labour source for agricultural activities.

Most of the farm families were made up of 8-9 people. Some of the family members, however, did not live on the farm. These were either grown ups working in various towns in Kenya or were young stars in boarding schools.

All the farmers interviewed had access to education for their children (with access to primary education being 100%). Most of the farmers also had access to health services provided by public dispensaries or private clinics. Some of the dispensaries have been put up by the Kenya wildlife services, particularly for those farmers living in the neighbourhoods of the Lake Nakuru National Park as a way of sharing the proceeds accruing from wildlife conservation. The Kenya wildlife Services has also assisted in putting up schools, particularly primary schools.

Labour used for agricultural activities is mainly on farm, but there were also reported significant cases of labour hiring. Some of the farmers also used machinery such as tractors as a source of labour on the farms.

4. DISCUSSION AND SCENARIO SIMULATIONS

Figure 2 below is a map showing a section of the study area for which GIS modelling and scenario simulations were carried out.

The area numbered 1 located to the southwest of Lake Nakuru extends to areas such as Njoro, Molo, parts of Rongai and parts of Mau Narok. This is a high potential area principally suitable for agricultural production and intensive livestock production activities. Prior to independence, the area was mainly used for large scale maize and wheat production and for potato production and intensive dairy cattle management. The area has since been sub-divided into small-scale farms but remains an intensive agricultural area producing plenty of maize, wheat, potatoes, pyrethrum and a host several horticultural products.

Area 2 is low-lying flat lands moderately high potential. Soil erosion risks and rates are low with the major economic activity being agricultural production. The area is mainly used for medium scale maize production and dairy cattle keeping.

Area 3 comprises the Lake Nakuru National Park famous worldwide for the flamingo birds including Lake Nakuru, which forms part of the park. The study revealed an overpopulation of herbivores exerting lots of pressure on the vegetation within the park. The scenario is worsened by the electric fencing of the park which does not allow free movement of the animals. The extensive human settlement in areas surrounding the park, indeed, complicates future management of the area. As a matter of fact, there is already wildlife-human conflict as those living near the park often experience massive destruction whenever the animals break loose from the park.

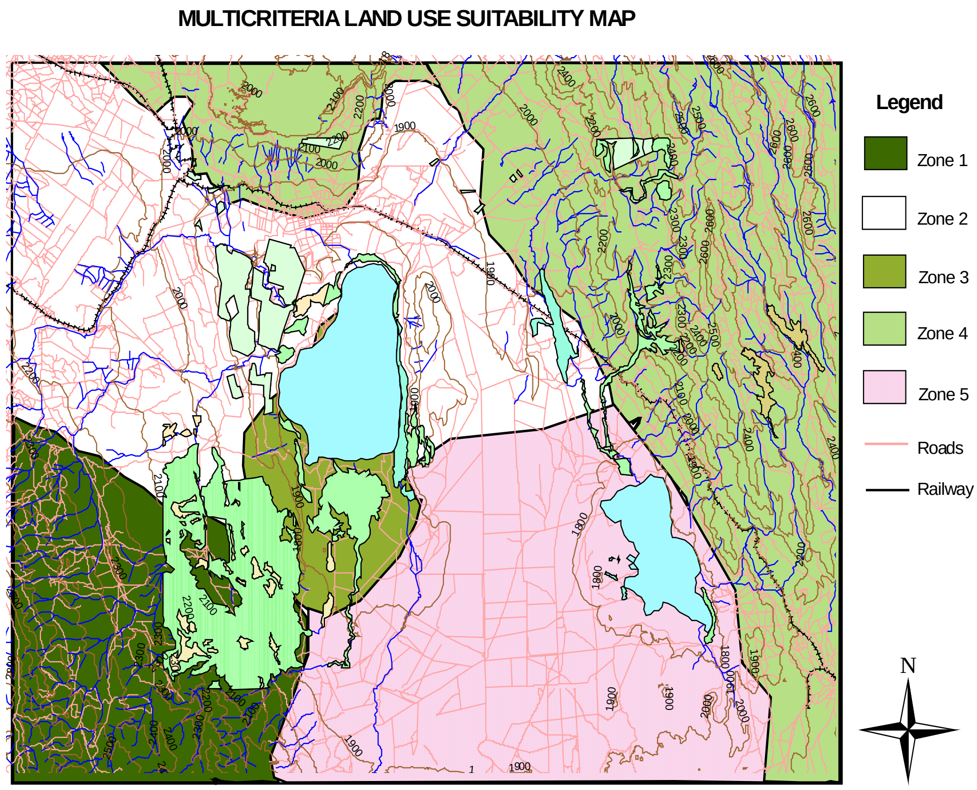

Figure 2. Map showing a section of the study area for which GIS modelling and scenario simulations were carried out

Area 4 is highly mountainous some of the parts having steep slopes that are generally not suitable for agricultural production. The usage of this area calls for extensive conservation measures to avoid degradation. Afforestation as well as other conservation measures such as contour farming, terracing among others should be encouraged for sustainable utilisation of sections of this area. In fact as a matter of policy, higher up the mountains/hills should be conserved as forest areas in order to maintain them as water catchments.

Area 5 comprises low potential rangelands. This area was, in the past, used as large-scale ranching area for beef production. As late as the 1990s most of the area was used for the same until one of the ranches belonging to the Agricultural Development Corporation was subdivided into small-scale units for sedentary farming. The new farmers have brought in their high potential farming practices whereby they are growing maize and other crops with very high failure rates as deduced from interviews during the field work. Indeed the area carries some of the most degraded parts of the study area and, therefore, there should be concerted efforts towards afforestation and reforestation aimed at environmental rehabilitation and conservation. From the simulations the area should be left for livestock production under ranching as it were before or alternatively, the area could be better off becoming part of the Lake Nakuru National Park hence becoming a protected area. Also noted was the livestock (human)-wildlife land use conflict in the area. In fact, currently, livestock-game ranching on the same farms is being practised by some of the large-scale farmers.

5. CONCLUSION AND FUTURE WORK

The Centre intends to undertake putting together all the data sets from all collaborators so that the prescribed GIS conditions can take place for the integrative analyses and further simulations. One of the actions to be taken is the land capability and suitability analysis that give the best alternative for achieving a good Decision Support System for this Project. Land capability, defined as the inherent potential of an area to produce specified goods and services e.g. agriculture, forestry, grazing, etc. is determined by the number and extent of site properties known to impose limitations on the specified use. These include topography, soils, moisture availability, among others. For example to classify land according to its capability to support sustainable rain-fed agriculture the following limitations are considered: altitude, slope, soil type, soil depth, and soil surface texture. The altitude and slope maps can be developed from this assignment from the digitised contours by generating the digital terrain models (DTM).

In-depth research to shed some light on the long-term implications, on the environment, of changes in land use systems from rangeland use to sedentary agriculture as well as the change from forestry to agriculture needs to be carried out. It is also important that studies be carried out to give insight in the current land use practices on the general productivity of the area, in view of the fact that crop yields have been declining with time.

ACKNOWLEDGEMENTS

The authors thank, most sincerely, the European Commission who funded the project. They, too, acknowledge the effective coordination by Prof. Enroco Feoli of Botany Department, University of Trieste in Italy and would like to equally thank the collaborators from the National Museums of Kenya and the Institute of Resources Assessment (IRA) of the University of Dar-Es-Salaam. They would also like to thank the various data sources that made it possible for the implementation of this project, among them the Department of Resource Surveys and Remote Sensing, Ministry of Agriculture, Kenya Government and the FAO AFRICOVER Project for the cooperation given in the execution of the Project. The efforts made by Miss Caterina Toufuluti, Mr. Julius Ikuha and Mr. Moses Yatich were quite helpful in the implementation of the Project.

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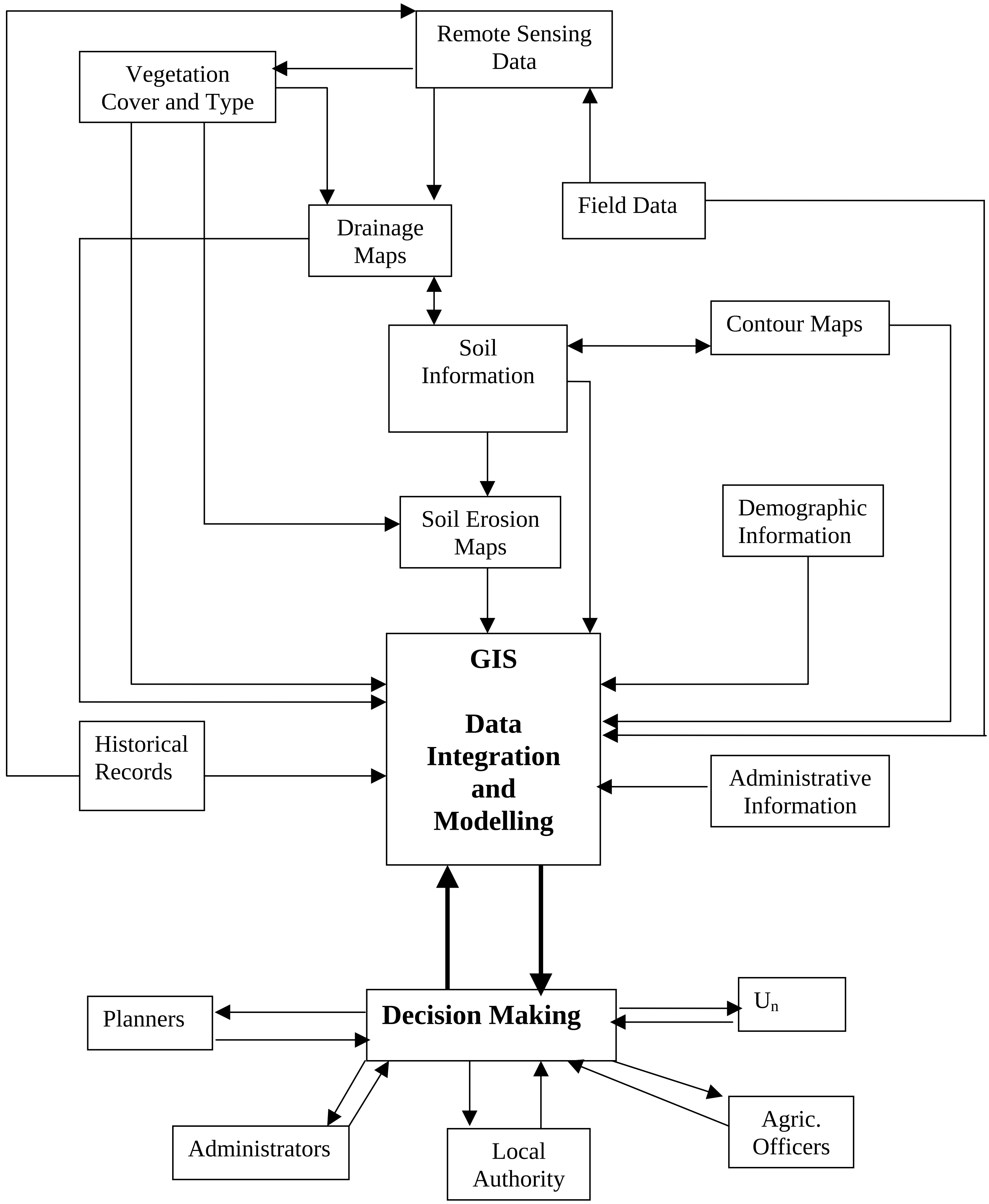
APPENDIX A. DATA INTEGRATION FOR DECISION MAKING IN DRY LAND MANAGEMENT



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