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Applications of Geographical Information Systems in Economic Analysis: A Case Study of Uganda

N. Vijay Jagannathan
Hideki Mori
H. M. Hassan

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N. Vijay Jagannathan and Hideki Mori are Consultants to the Environment Department of the World Bank. Hassan M. Hassan is a Senior Environmental Specialist, Environment Department, the World Bank.

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APPLICATIONS OF GEOGRAPHICAL INFORMATION SYSTEMS IN ECONOMIC ANALYSIS: A case study of Uganda

ABSTRACT

There is growing evidence that socio-economic factors have been affecting the use of renewable natural resources in an unsustainable manner. This study explores whether a spatial approach can serve as a conceptual framework to integrate natural resources and socio-economic concerns, taking Uganda as the case study.

Uganda has been selected primarily because a spatially referenced natural resource database for the country has been made available by UNEP. The study shows that despite the extremely complex nature of inter-actions between the physical environment and the socio-economic system, many observed spatial and temporal changes can be traced to socioeconomic factors. The findings are not necessarily definitive; rather they illustrate a method of analysis that should be developed through further research.

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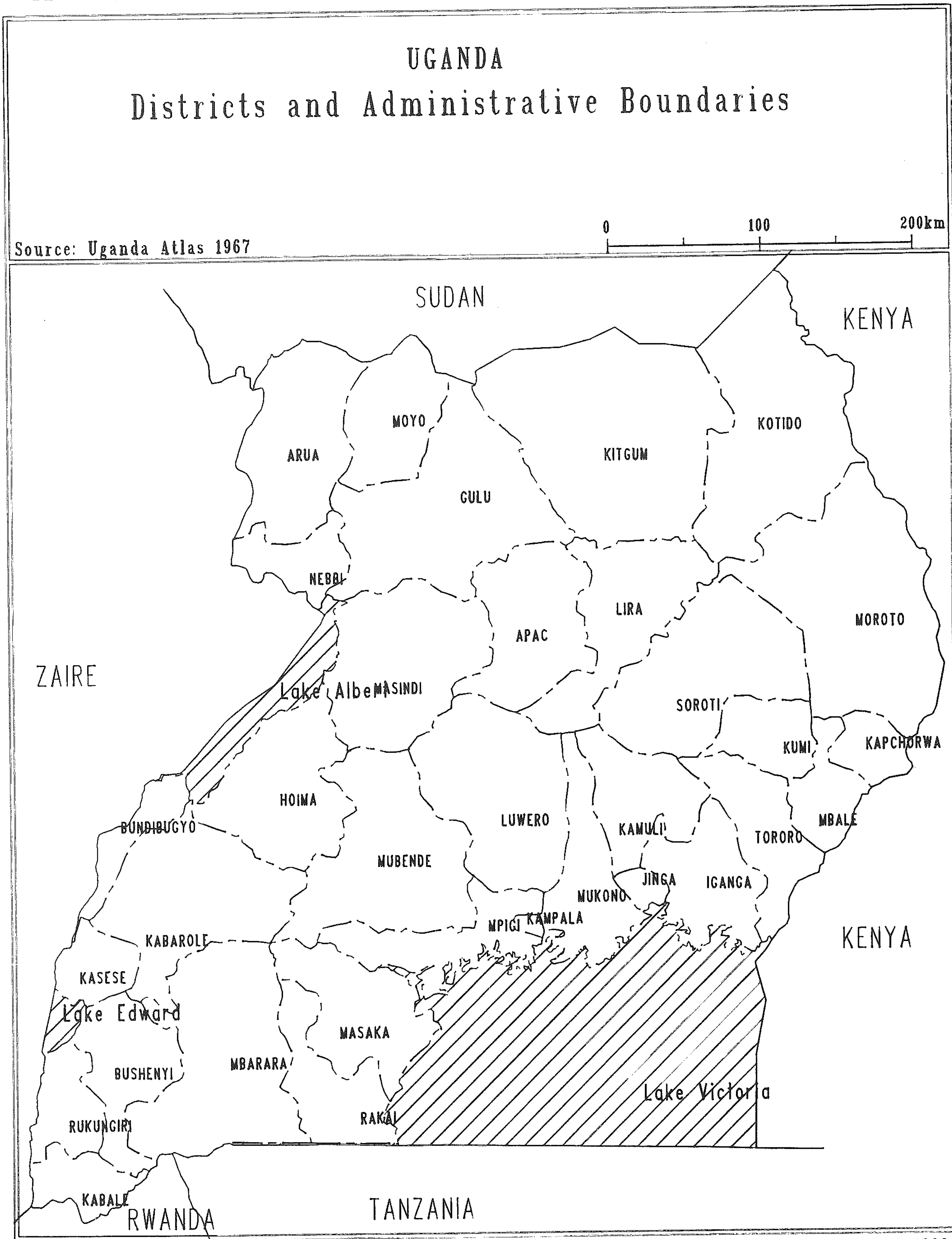

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APPLICATIONS OF GEOGRAPHICAL INFORMATION SYSTEMS IN ECONOMIC ANALYSIS: A case study of Uganda*

1. INTRODUCTION

1.1. Over the past years, widespread degradation of the renewable natural resource base has taken place in most developing countries, and there are indications that this threatens the sustainability of economic growth. It is increasingly recognized that public policies at the Central Government level may, often unwittingly, encourage such degradation. Understanding the relationships between various government policies, other socio-economic variables and physical manifestations of environmental degradation is necessary if appropriate remedial measures are to be taken, and environmentally sustainable economic and other social policies are to be identified.

1.2. At present there is no commonly accepted method available to alert policy makers to the environmental consequences of their actions. The objective of this study is to test the applicability of spatial impact analysis, using Uganda (Plate I) as a case study. The underlying premise of this study is that many socio-economic and natural resource attributes are area-specific in nature. By utilizing a spatial framework, the data handling capabilities of Geographic Information Systems (GIS) can be used to understand linkages between the economic, demographic and natural resource factors.

1.3. GIS may be viewed as an information system in which most of the data are spatially indexed and geo-referenced. A set of procedures is then devised that is able to answer explicit queries about data sets within the system, and to identify their interactions with other available data sets within the system. GIS is generally designed to satisfy one or more of the following requirements (S.Menon et al. 1987):

(i) handling large multi-layered, heterogeneous data bases of spatially indexed data;

(ii) query the data set about the existence, location and properties of a wide range of spatial objects;

(iii) handling queries that permit the system to be interactive;

(iv) allowing sufficient flexibility in the system to satisfy user needs;

(v) allowing the user to learn more about inter-relations between spatial objects.

1.4. For this study, (v) is of particular importance. The capabilities of GIS are utilized to understand whether there are systematic linkages between natural

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*We gratefully acknowledge UNEP's permission to use the data base for this pilot study.

resource and socio-economic attributes for the same geographic locality. The data base provided by UNEP and generated by the study now includes the following layers:

* Political and district boundaries;
* Soil:
  - -- productivity
  - -- erosion
  - -- slope
  - -- suitability;
* Agro-ecological zones;
* Land use/land cover 1973;
* Land use/land cover 1986;
* Population density by district (1980);
* Infrastructure, including road impact areas;
* Livelihood systems;

1.5. Different overlays of information were utilized to study changes in both the spatial and temporal dimensions by using pc-ARC/INFO, ERDAS, dBASE IV, and Quattro. All raster data were first transformed to vector format before being used in the analysis.

1.6. Uganda was selected primarily because UNEP, the Regional Remote Sensing Center in Nairobi and the Ministry of Environment of the Government of Uganda have recently completed an exercise to develop a natural resources data base of that country on a popular geographic information system. The UNEP study utilized (i) the Atlas of Uganda (1964 and 1967 editions), and (ii) the visual interpretation of remote sensing images of 1973 and 1986. This data set was supplemented by the socio-economic data digitized from data available within the Bank, using the facility of the Geographic Information Processing Center in the Environment Department.

1.7. The issue for examination in this paper is to explore whether the spatial dimension should be brought into macro-economic management of natural resources. The study could be considered as a pilot attempt to integrate ideas from economics and natural resource analysis by undertaking a diagnostic analysis of inter-temporal changes in land use at a regional level, and explaining the causal processes.

1.8. The paper is divided into six sections. The second section proposes a method of spatial analysis by which economic and natural resource variables can be integrated. The third section describes briefly some features of the Ugandan economy of interest to the study. The fourth section analyzes land use in Uganda between 1973 and 1986 both by regions and by ecological zones. The fifth section conducts a diagnostic analysis of changes in area cleared for farming/livestock rearing to understand the causal processes at work. The sixth section discusses some issues for further research.

2. A METHOD OF SPATIAL ANALYSIS

2.1. The research methodology draws on the pioneering work by Nijkamp and Van Pelt (1987), in which the authors described and tested a framework for spatial impact analysis of policy options in developing countries. The underlying premise is that economic, demographic and natural resource data attributes can be expressed in spatial terms as features, labels and thematic components (Nijkamp and Scholten 1989). Any of these spatial units can be treated as geometric features on the earth's surface, and specific economic characteristics, such as GNP, population, land area etc. can be described as attributes or layers of information associated with particular areas.

2.2. For example, an area on the earth's surface may have an attribute called "country name", as in the World Bank's Bank Economic and Social Database (BESD). The country is then further described as, "Uganda" and "Uganda GNP per capita". At this level of aggregation, the lines separating one polygon from another are called national boundaries. Disaggregated subdivisions get labelled as provincial, district, urban or even village boundaries. Natural resource attributes (such as conifers, highland wood, mangrove swamps etc.) could also similarly be spatially referenced to match these subdivisions. The map or computer screen is then able to show the unique features of each area, consisting of many layers of data. Essentially, the procedures involve expressing natural resources and socio-economic data attributes in terms of common geographical areas or space. While so far, natural resource databases are, by convention, compiled on bio-physical features, and socio-economic data bases are aggregated by political/administrative units, there is in theory, no problem in expressing all data sets in terms of common bases and scales.

Procedures for preparing compatible data bases

2.3. Interpretation of any information relies largely on the quality of the basic data. Available spatially referenced data sets are seldom of common scale or level of accuracy. For example, satellite-collected natural resources data are themselves at different levels of scale and precision. Topographic and thematic maps also vary in scale and accuracy, depending on the methods of data compilation, and objectives; from atlas maps at 1/1000,000 through national map series at about 1/100,000 and 1/50,000, to project level maps at 1/10,000 and larger. In this pilot study, which has attempted to raise issues for further research, the level of analysis was restricted to an aggregative, regional level.

2.4. Apart from scale problems, data interpretation problems also present issues for research. On the one hand, for example, remote sensing images are largely based on value-free principles (although ground truthing of data brings in a subjective element into the research). On the other hand, many socio-economic characteristics, such as poverty, living standards, physical quality of life index etc. are often subjective, value-laden descriptions. Other socio-economic data on national income, occupational distribution, cost of living indices etc. are also, at best, approximations of economic attributes. In Uganda, these data sets had serious deficiencies in coverage and accuracy. Despite these caveats, spatially referenced data sets are shown in this study to serve a useful role in economic analysis.

2.5. Once spatial referencing of data sets is completed and scaled to compatible levels, generating computerized overlays of data is a mechanical task. Area statistics, which were generated through this task, formed a basis for studying the inter-relations between spatial attributes in Uganda.

2.6. The problem in Uganda, as in most developing countries, is that available spatially referenced data sets are limited in scale and precision. A review of official and World Bank project documents in Uganda indicates that:

a) Demographic variables (population growth, migration, urbanization, etc.) could be disaggregated only to the level of districts.

b) Ecological potentials were available in terms of climax vegetation categories generated by a study in 1964 (discussed in section IV).

c) Economic variables exhibited the widest variation in scale and precision[1]. Specifically;
   - 22 categories of land use were available at the level of ± 2 km horizontal error.
   - Major farming systems were loosely defined regions extending over several districts.
   - Physical infrastructure (roads, railways, power lines, processing facilities, etc.) were obtained from Uganda Atlas (1962) and World Bank maps at different scales.

2.7. The choice of a district as the basic unit of analysis was considered appropriate for three reasons. First, some socio-economic data are available at this level in the decennial population census and with government departments. Second, as most districts have large areas, varying between 4000 and 10,000 square kilometers, they are big enough areas to absorb interpretation errors likely in the data sets. Third, districts in Uganda are the lowest administrative units having line offices of important departments and ministries. In the years to come, with improvements in socio-economic data collection, one can expect them to be functioning as key nodal units for natural resource management.

2.8. The procedure used in this study is called the GIS overlay. This method composites two or more existing thematic maps. For example, assume that one thematic map X, of income levels has three classes, A, B and C. The spatial distribution of these classes is shown in Map X. The attributes A,B and C define three homogeneous sub-regions, X1, X2 and X3 respectively. Map Y is a second thematic map of say, soil type, again separated into sub-regions Y1, Y2 and Y3, with their respective attributes I, II and III. A simple overlay process generates a third map (Map Z), with logical intersections of the above two themes in a spatial context. Subregions of the Composite Map keep original attributes

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[1]The few detailed village or regional case studies available (ILO 1984, USAID 1984, Marvin 1978) were based on a few sample villages, and obviously could not be generalized for the whole country.

of Maps X and Y. GIS overlays are a technique that can be used to divide areas based on multiple criteria.

2.9. Figure 1, Figure 2 and Figure 3 is a graphic representation of the overlay process. Behind the computer screen, sub-regions of each map are linked to corresponding records of the relational database management system (DBMS). The internal data structure of the vector-based GIS is similar to any standard database package, as shown in a tabular format below (Table 1-1,2,3).

2.10. Conceptually, conventional statistical analysis methods can be directly applied once spatial information has been reduced into a tabular format. However, owing to data unavailability, the exercise remained mainly at the diagnostic level. Spatial attributes of economic systems were described, subject to data availability, in terms of specific characteristics.

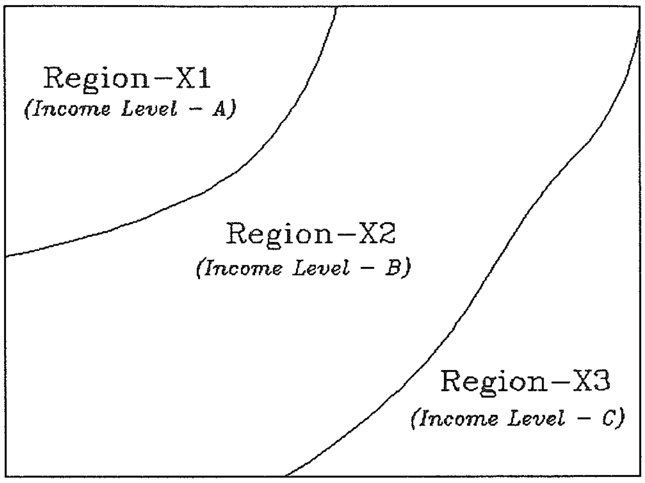

Figure 1:Map-X

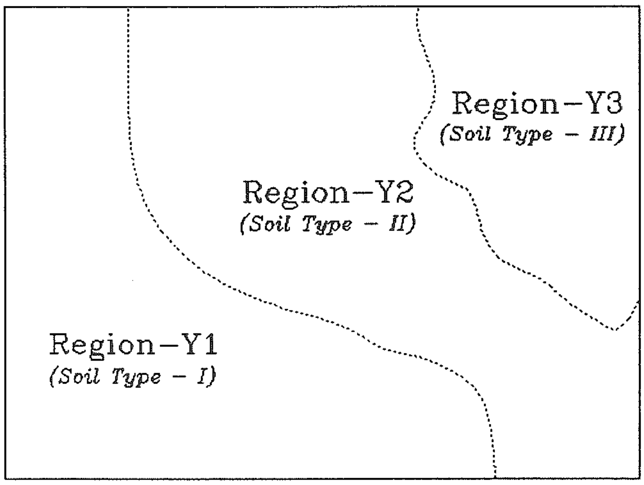

Figure 2:Map-Y

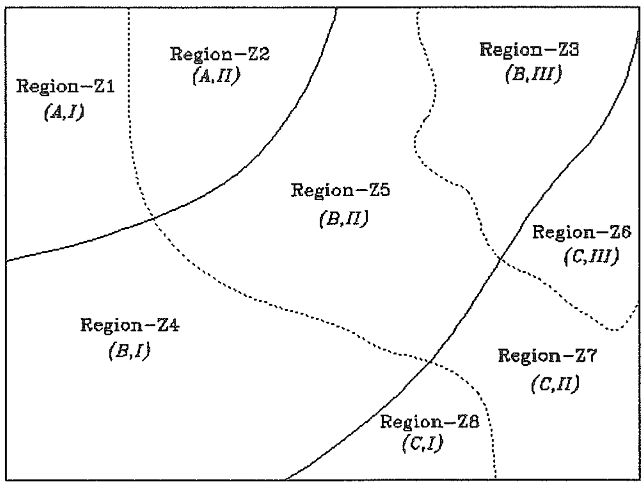

Figure 3:Composite Map-Z

<u>A method for diagnostic analysis</u>

2.11. An attempt was made to classify data in three sectors -- economic, demographic and natural resources. After the preparation of compatible data bases, temporal changes in natural resource patterns were identified so that the causal factors were analyzed. The conceptual framework used was a modification of the Nijkamp and van Pelt model, which used a systems approach to trace spatial impacts of economic policies in an urban region. Their model had four subsystems - economic, demographic, social and facilities. In this study, the following modifications were made to their model:

* Inclusion of a natural resources subsystem, which describes the spatial characteristics of land and water use;

Table 1: Database Structure of GIS Overlay

Table 1-1 : DATABASE FOR THE MAP X

Region	Area	X (income level)
X1	138	A
X2	635	B
X3	227	C

Table 1-2 : DATABASE FOR THE MAP Y

Region	Area	Y (soil type)
Y1	391	I
Y2	417	II
Y3	192	III

Table 1-3 : DATABASE FOR THE COMPOSITE MAP Z

Region	Area	X (income level)	Y (soil type)
Z1	113	A	I
Z2	25	A	II
Z3	141	B	III
Z4	268	B	I
Z5	226	B	II
Z6	51	C	III
Z7	166	C	II
Z8	10	C	I

* Merging of the facilities subsystem (social and physical infrastructure) with the economic subsystem, because the former is dependent on public investment outlays;

2.12. The modified framework also assumed that changes in the demographic subsystem, such as increase in labor supply, have a primary impact through the monetized (organized or informal) sector of the economy (see Chadwick 1987)[2].

2.13. The economic sub-system in the above chart can be described in spatial terms as locational nodes of economic activities and territorial networks that connect these nodes (Riddell 1985). At each of the locational nodes, marketplace organizations govern the physical organization of production and exchange, which are in turn, determined by functional, social and legal factors. Depending on the combination of these factors, a spatial market system acquires differentiation, and a hierarchy of market centers evolves (Painter 1987). The social subsystem of the Nijkamp-von Pelt model, therefore, has been incorporated with the economic subsystem through the concept of marketplace organizations.

2.14. For example, if the producer prices for cotton increased in Uganda, the areal impacts would depend not only on technological factors, but also on the spatial organization of cotton production. The factors influencing such organization then becomes:

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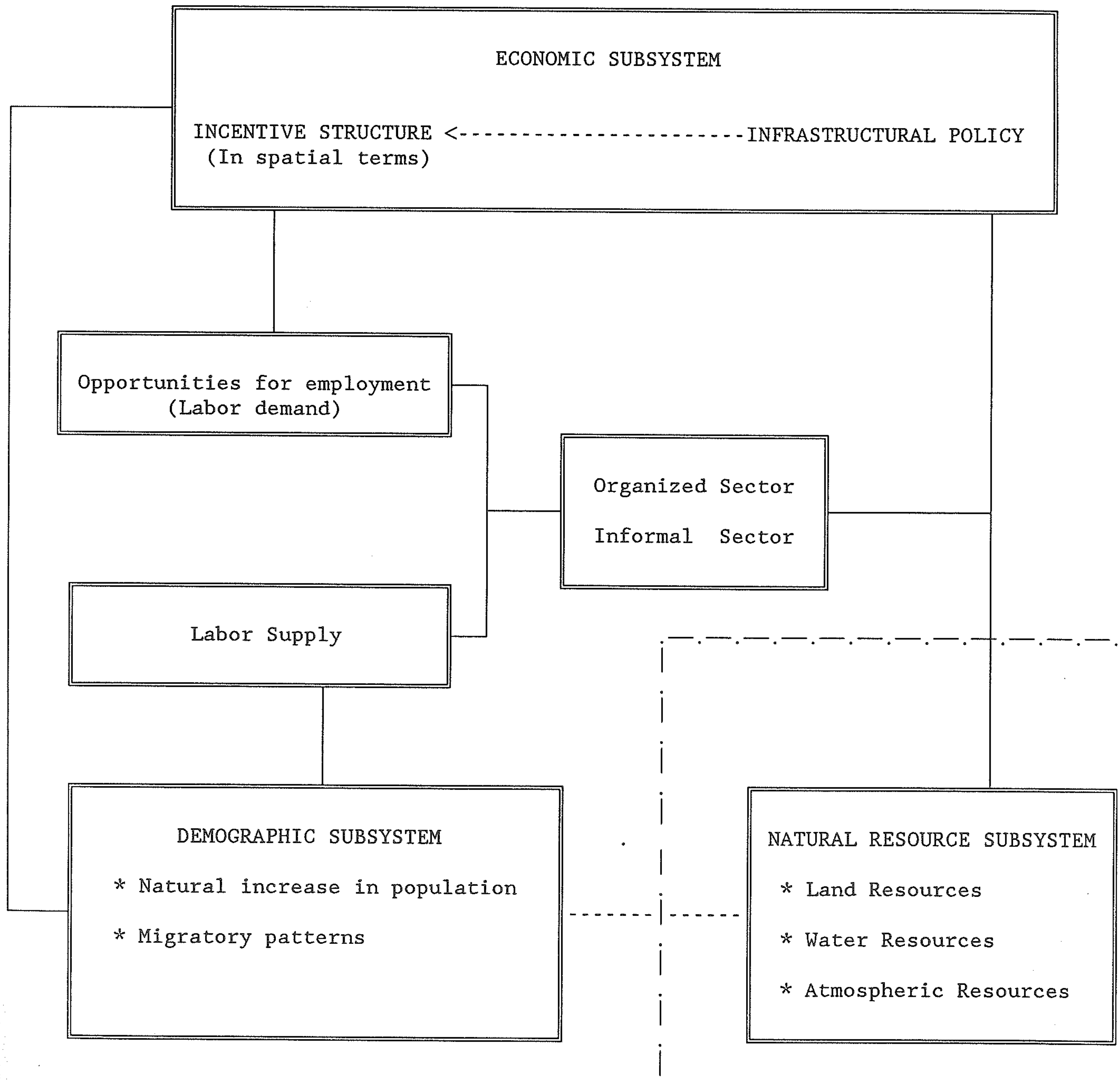
[2] However, as indicated by dotted line in the chart below, there could also be a non-market linkage between the demographic and natural resource subsystems. For example, in poor or subsistence communities, gathering of fuel wood from common lands, squatting on public lands, farming on marginally productive lands could take place.

Table 2: A Systems Approach



* Forward linkages to cotton ginneries;

* Backward linkages to input supplies;

* Accessibility to markets or functional linkages;

* Availability of land (depending on prevailing practices for leasing in land or institutional linkages);

The incentive structure in spatial terms incorporates all these factors. Some of them are not measurable on a cardinal scale, but could be described in ordinal or binary scales. The computer system can, by using overlays of data attributes, identify areas where different combinations of factor attributes are present. Finally, if these areas are then overlaid on a land suitability map, locations or areas where cotton cultivation are (i) likely to expand, and (ii) best suited for expansion can be identified. To sum up, economic, institutional and social linkages, physical and social infrastructure are represented as overlays of features, labels or thematic components. Composite maps of these overlays describe how the incentive structure gets translated to spatial impact areas. These linkages determine the opportunities for employment or labor demand in the area. In a similar manner, the demographic sub-system was spatially referenced to show areas of population density and growth.

2.15. In the analytical framework, opportunities for employment are assumed to be dependent on the technology level and capital availability. These opportunities determine labor demand in both organized and informal (magendo) sectors. Although labor and capital markets are equally important to determine how economic opportunities emerge, the framework takes the capital market to be exogenous, and examines spatial impacts of economic activities on the natural resource base.

2.16. For the diagnostic exercise, the following procedure was adopted:

-- Land use for 1973 and 1986 were compared with each other, so that changes in renewable natural resource areas were estimated.

-- The study areas was then narrowed to micro-regions that appeared to have undergone major changes in renewable natural resource uses. For example, lands cleared of vegetative cover, area changes under agriculture, regrowth of vegetative cover were some of the identified categories.

Causal factors discussed in this desk study, however, requires confirmation by field-level investigations.

3. ECONOMIC CONDITIONS IN UGANDA 1973-86

3.1. During the period relevant to this study (1973-86), the Ugandan economy experienced several political, economic and climatic problems. There are indications, however, that since 1986, the law and order situation has improved, and that macroeconomic stability has been achieved. In this section, a brief description is given on the state of the Ugandan economy during the study period.

3.2. Uganda, between 1973 and 1986, witnessed a steady deterioration in almost all major economic indicators of economic welfare. Law and order problems resulted in several parts of the country experiencing severe dislocations in economic activities. Refugee population movements from West Nile (Arua and Nebbi districts), Mbarara and Ankole districts forced several ethnic groups to flee across international borders. In other more centrally located districts, such as Luwero, Mubende and Mpigi, entire communities were affected by looting and depredations of security agencies (Hansen and Twaddle 1988). Several documents, notably Seers (1979), World Bank (1982), USAID (1984), Govt. of Uganda (1987) have cataloged the extent of economic and social disruption in the country, which until the mid-sixties, had one of the best developed social and economic infrastructure in sub-Saharan Africa.

3.3. Drastic reductions in cash crop production, collapse of the transport infrastructure, and shrinkage in industrial output, were economic manifestations of the political crises. These together led to a decline in living standards that affected all regions of the country. In the border areas adjoining the more robust Kenyan economy, smuggling of goods, notably Ugandan coffee became widespread, depriving a bankrupt exchequer of much needed hard currency. Markets and institutions of the organized sector ceased to be effective during the period 1973-86; and economic activities in even the advanced regions of the country shifted to the thriving magendo or parallel economy.

Collapse of cash crop production

Table 3: Index Numbers of Cash Crop Production in Uganda

	1970	1975	1980	1985
Coffee	100	99	67	77
Cotton	100	37	15	16
Tobacco	100	116	93	16
Tea	100	101	8	3
Sugar	100	17	11	2

Source: World Bank (1982), Govt of Uganda (1987)

3.4. The most noticeable decline has been in cash crop production, which traditionally, not only generated most of Uganda's hard currency, but also provided cash incomes for most small holders in the rural sector. Table 3 summarizes these trends between 1970 and 1985.

Table 4: Costs and Returns of Crop Production (in post devaluation shillings)

	Price per kg	Net return per (i) hectare	(ii) person-day	Cost of non-labor inputs
Groundnut	120	68,231	545.8	12,000
Bananas	16	53,000	363.0	-
Maize	20	18,055	164.1	600
Coffee	35	39,273	187.0	-
Cotton	35	2,150	16.8	500
Tobacco	60	240	3.3	10,012

Source: World Bank files

3.5. A report on costs and returns to crop production in Uganda, obtained from World Bank correspondence files (1985-86) is shown in Table 4. Both in terms of net returns per hectare and net returns per person-day, coffee has been the only cash crop that offered comparable returns to food crops.

3.6. In the period between 1971 and 1985, Uganda's vehicle fleet was almost halved from 44,500 to 24,195, and the decline in freight carried by the Railways was equally dramatic (World Bank 1982, Govt of Uganda 1987). The impact of the transportation crisis was particularly noticeable in the cotton and tobacco-growing belts in northern and central Uganda in terms of decrease in production because of the dependence of these crops on mechanical transportation during both production and marketing.

3.7. The sharp decline in production of cash crops had two important consequences. First, Uganda was reduced to an almost complete dependence on coffee for all its hard currency earnings. In 1971 coffee accounted for about 56 per cent of the value of Uganda's exports, and by 1978, this percentage share had climbed to 88 per cent, with the latest (1989) estimates being close to 97 per cent. Second, as crops like Cotton and Tobacco were providing the bulk of cash incomes for rural communities in the Northern and Western districts of the country, a collapse in production was a symptom of the disintegration of a commercialized market system (involving purchased inputs, use of mechanical traction, and some amount of vertical integration) (Hansen and Twaddle 1988). Carr (1982) has estimated that cotton acreage in 1969 accounted for about 35 per cent of cultivated area in Soroti and Kumi districts, while in the more northern districts of Uganda the percentage area was a substantial 25. In these areas cotton was the main source of cash earnings for farming households. An ILO study of tobacco in the West Nile districts in the mid-1970s, similarly, indicated that farmers in that region secured over 80 per cent of cash incomes from tobacco sales.

3.8. Production trends in food crops was somewhat better, although still below the peak outputs achieved in the early 1970s. Bananas, sweet potatoes, cassava and maize all appear to have reversed the production declines of the mid-seventies. Swamp rice production is also reported to have registered large increases in the densely populated districts, being attracted by the excess demand in urban areas. However, severe problems in acquiring even the simplest farming tools (hoes, pickaxes etc.) have forced farmers to regress in their production technology. In the densely populated districts already facing acute land scarcity, farmers have been forced to reduce fallow periods, which are considered essential if farmlands are to re-generate themselves under the prevailing farming system (Hansen and Twaddle 1988).

3.9. In the northern and northwestern districts, as plow spares and oxen replacements were unavailable, farmers were forced to revert from oxen cultivation to hand hoes. The collapse of the transportation system prevented these farmers benefitting from rapid increases in urban food prices in the southern districts (USAID 1984, Barry and Hughes-Cromwick 1980). In the densely populated districts bordering Lake Victoria, and in the Southwest, food crops could be readily sold for cash through the informal marketing systems that serviced urban food markets. However, food production occurred (a) under conditions of intense land scarcity, and (b) without improvements in farm technology (USAID 1984, Seers 1978). Land degradation and poverty have thus been observed in most districts of the country (USAID, 1982).

Decline in living standards

3.10. Economic conditions in Uganda between 1973 and 1986 can be characterized by reduced production of cash crops, problems of food insecurity in the northern districts, a collapse of the transport system, and a dramatic shrinkage in industrial production. The declines in living standards have, therefore, been pervasive, although some areas have fared worse than others. Even in the relatively better developed areas along Lake Victoria, households reported owning fewer consumer durable goods in 1984, compared to 1962. Urban areas fared no better, and Uganda is one of the few countries of sub-Saharan Africa that did not witness a massive increase in rural-urban migration in the last two decades. Although the growth of magendo or parallel economy provided some income opportunities, a highly unstable law and order situation, led to a small affluent minority extracting most of the rents generated in the process (World Bank 1982, Seers 1979, USAID 1984). For the average Ugandan high inflation, uncertainties in

Table 5: Factor Increase in Consumer Goods/Durable Goods Prices

	Factor increase 1962-84
Blanket	6000
Saucepan	320/300
Brick house	1000
Sugar	285
Salt	166
Kerosene	166
Hoe	250/376

Source: USAID (1984) p 117

market distribution of goods and services, and frequent breakdown of law and order contributed to a substantial decline in living standards.

3.11. Case studies from four districts of the country by USAID indicate that most rural communities adopted a multiple income earning strategy of subsistence farming on family holdings, inferior quality livestock rearing (wherever feasible), and very low-return off farm incomes for survival. Off-farm incomes (for cash) accounted for between 20 and 50 per cent of farmers' incomes (USAID 1984, Hamilton 1984).

3.12. To sum up, living standards collapsed throughout Uganda between 1973 and 1986. Except for improving literacy rates, there were no redeeming features among the country's social indicators. Increasing infant mortality rates, and an epidemic of AIDS attests to the decline of social infrastructural facilities. The collapse of the organized sector, growth of the magendo economy, looting and smuggling contributed to an almost complete reversal of the economic development process in the period under study. Perhaps in this sense Uganda's experience represents a 'worst case scenario', rather than a typical developing country experience. In any case, it would be instructive to examine how the natural resources of the country coped with an unremittingly gloomy picture of collapse of public security, growing population, increasing poverty and decaying infrastructure in the period under the study. In a situation of singular economic policy failures and population growth, the pressure on natural resources could be expected to have been substantial.

Plate II: Land Use in 1973

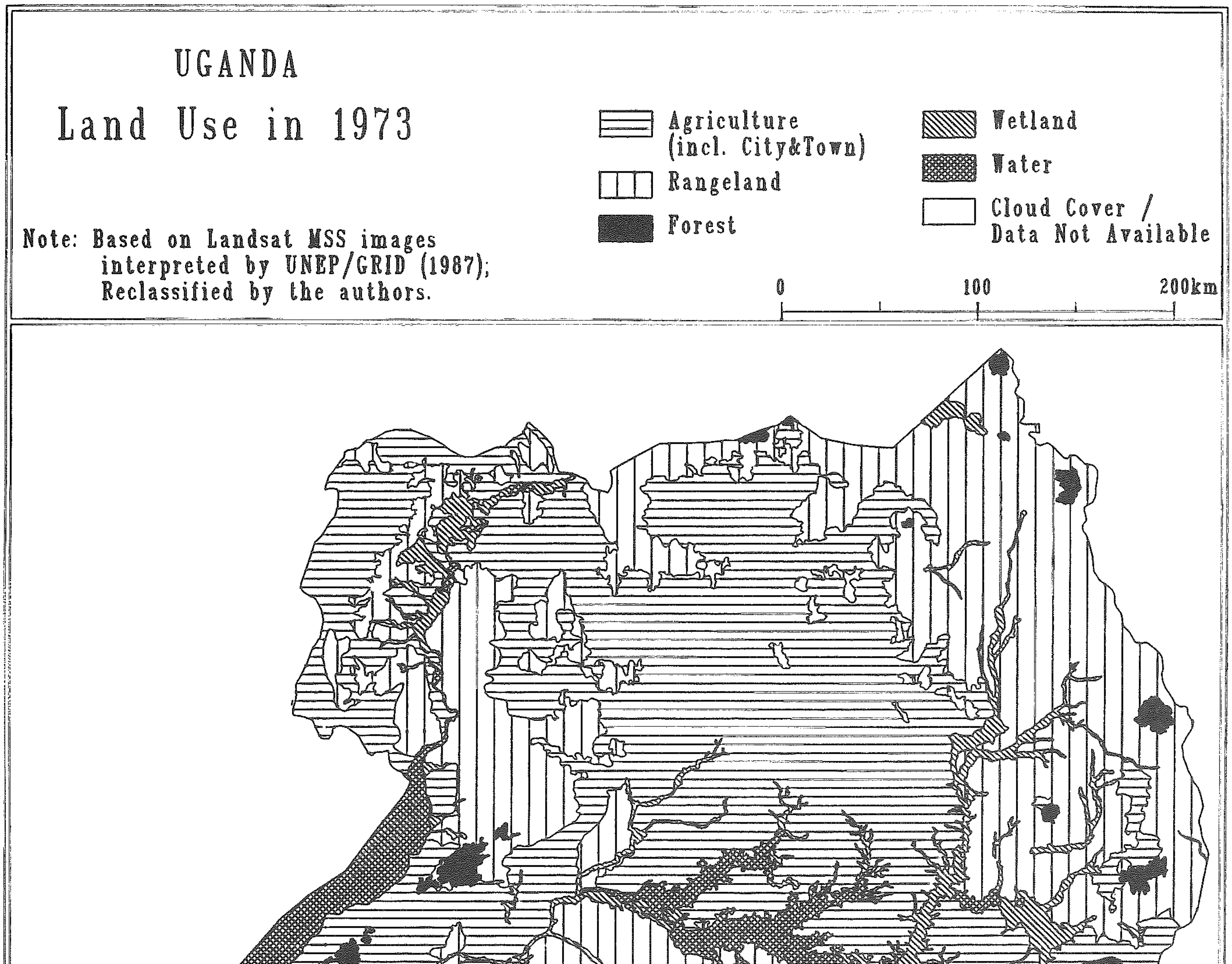


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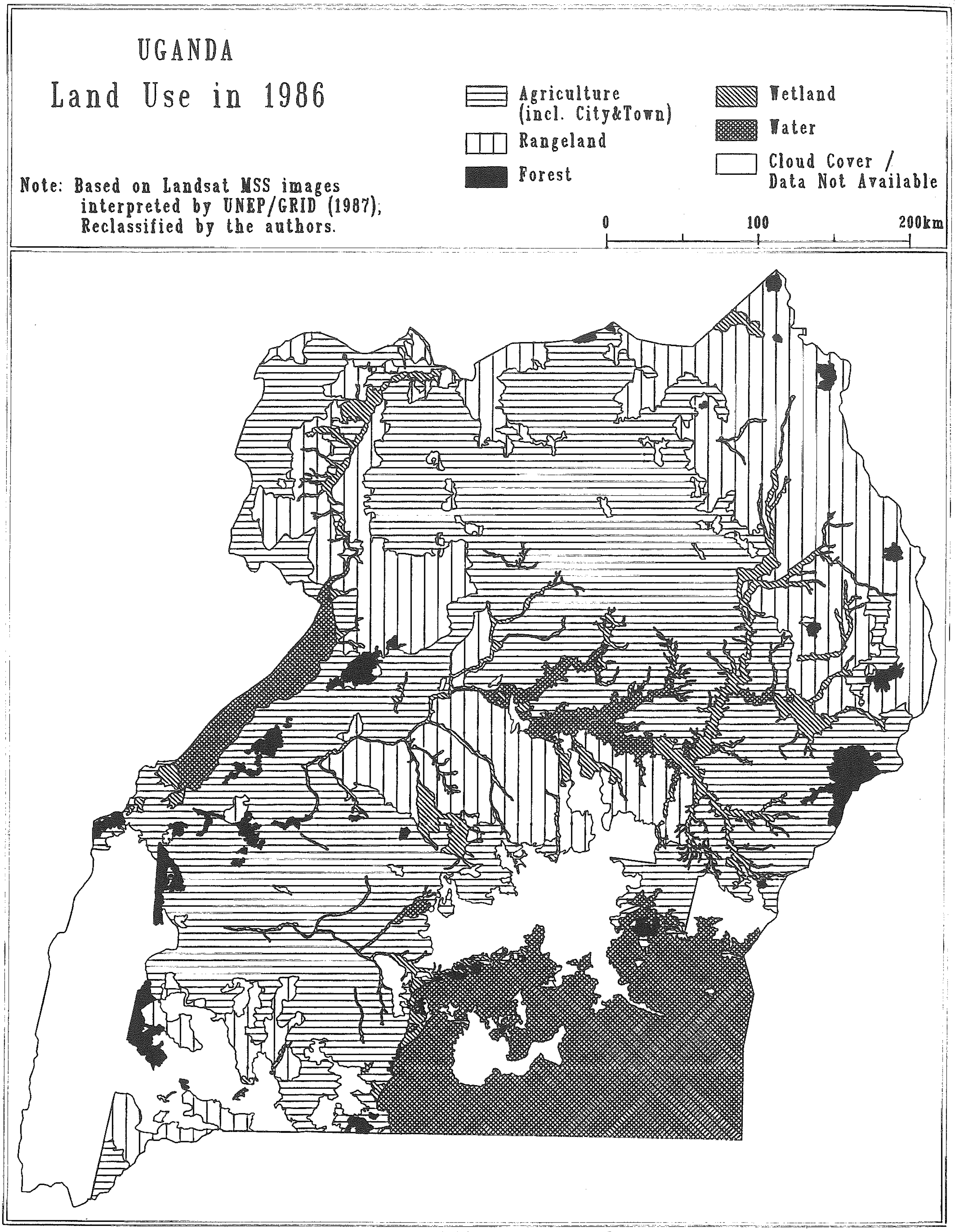
Plate III: Land Use in 1986



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4. CHANGES IN LAND USE IN UGANDA 1973-1986

4.1. Landsat MSS images for 1973 (Plate II) and 1986 (Plate III) have provided this study with spatial and temporal changes in land use, as well as statistics on land pressures in different parts of the country. In this section an aggregative analysis of the data set will be conducted to identify major features of land use changes as related to these pressures.

Pressure on land resources in Uganda

4.2. Based on the 1969 population Census, Seers (1978) had projected that by 1981, several districts of Uganda would be reaching 90 per cent of their land carrying capacities. In the less densely populated districts of the North and Northwest, rural out-migration was estimated to reduce the pressure of population to around 50 per cent of land carrying capacity. However, even in these districts, growth in livestock population, has greatly increased the combined pressure from farming and grazing on land resources (USAID 1982).

4.3. Landsat images of 1986 (Plate III) confirm the pressures of human settlements on land. Figure 4 shows that among the districts for which cloud-free data were available, five had more than 90 per cent of land area cleared for agriculture/grazing. This zone of highest clearing is visible in the densely populated area around Lake Victoria districts.

4.4. Between 1973 and 1986, several districts in the Northern Savanna belt also appear to have exhibited vegetation clearing exceeding 75 per cent. Most of these districts are located in areas that had been exposed to repeated droughts in the last decade (USAID 1982, Barry and Hughes-Cromwick 1980). Districts with below 20 per cent area under agriculture comprised two districts of the under developed Karamoja region (Northeast Uganda), Bundibugyo on the Western border with Zaire and Luwero district in Central Uganda.

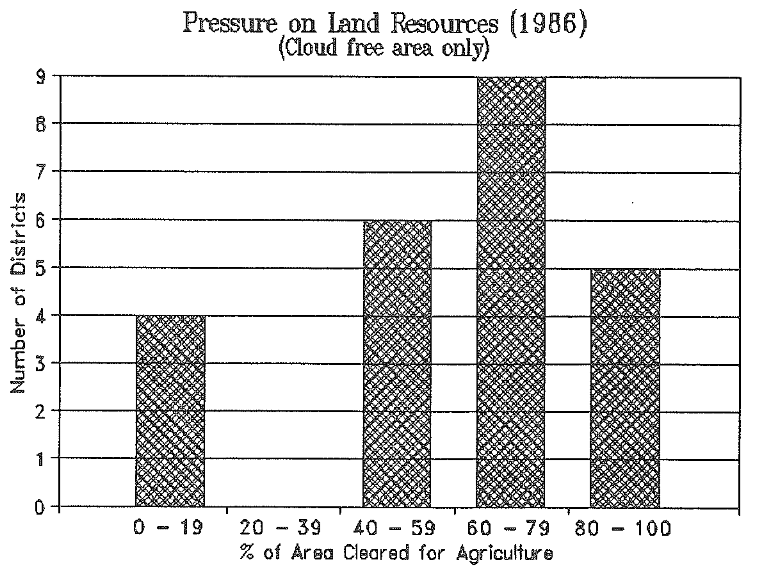


Figure 4

Changes in land use 1973-86

4.5. Table 6 shows land use changes between 1973 and 1986 in the seven major regions of the country for which cloud free data were available. What is interesting is that at an aggregative level, net clearing of vegetation for

Table 6: Land Use Changes between 1973 and 1986

Region	No.of districts	Change in (i) Agri/Livest	(ii) Natural vegetation
		------- (sq. kilometers)	--------
West Nile	3	-576	+897
Northern	4	+3446	-3626
North west	4	+66	-76
Western	4	-2651	+1966
Mount Elgon	2	+410	-699
Southern	5	+809	-984
Karamoja	2	-22	-36
Total	24	+1482	-256

farming and livestock was barely 1 per cent of the total sample land area. Even more significant is the fact that only nine districts have accounted for about 90 per cent of changes in agricultural area. If these nine districts are excluded, for the remaining fifteen districts, virtually no aggregative change in area cleared of vegetative cover appears to have occurred.

Vegetative cover and land use

4.6. An ecological study by Langdale-Brown et al (1964) contains a detailed mapping of climax vegetation cover for the whole country. 21 ecological zones based on actual and potential distribution of climax vegetation provided a baseline data source. Climax vegetative cover provides an "ideal" ecological classification, which can give an idea of the vegetation potential of an area (Makin and Innes 1986). Comparing the actual land use derived from remote sensing with this ideal scenario enables one to identify:

(a) vegetative zones that have felt the maximum pressure of human settlements;

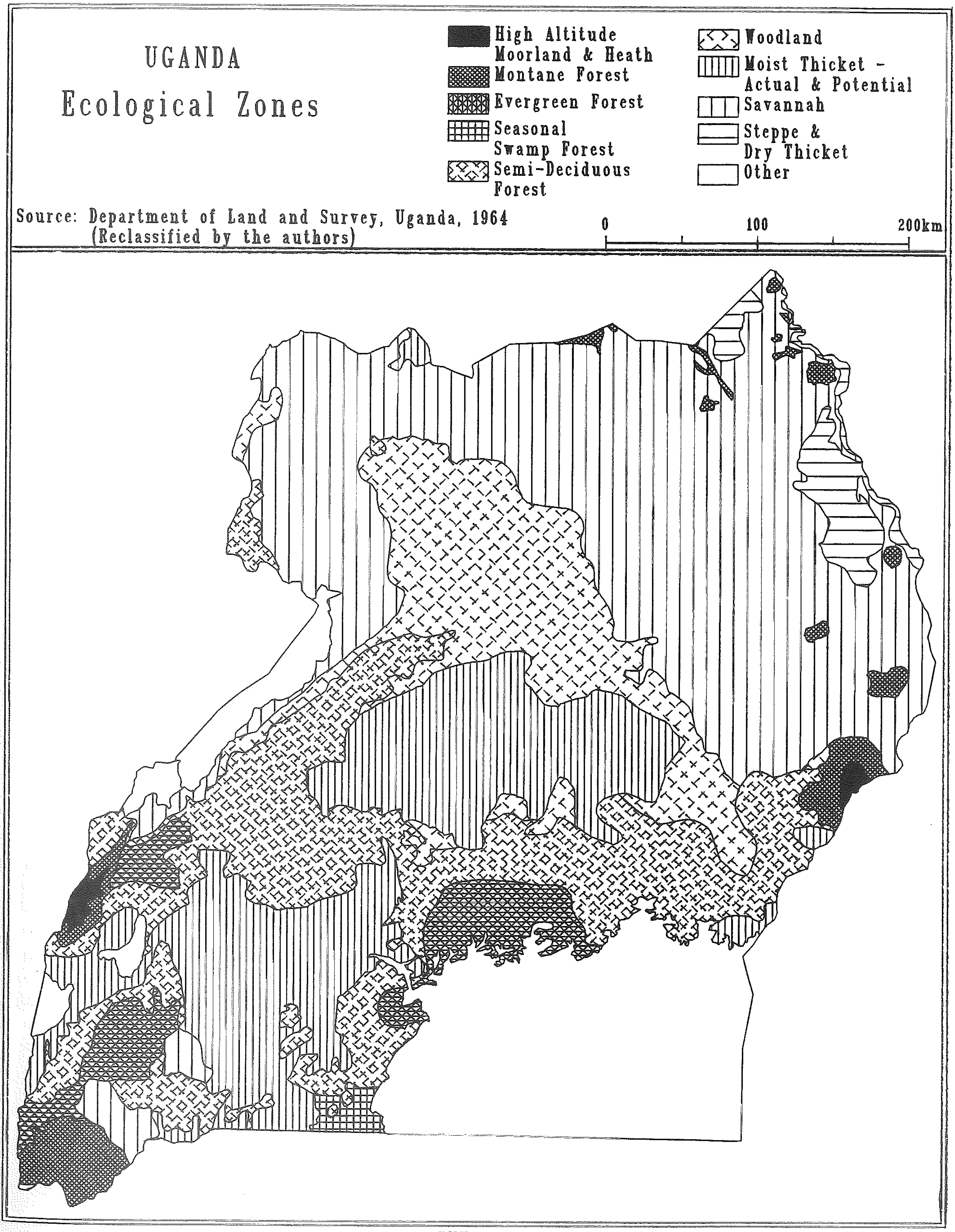
(b) the opportunity costs of land use changes in specific ecological zones. Areas best suited for forests are also often best suited for agriculture. A patch of semi-deciduous forests in a heavily populated district, for example, has a different opportunity cost compared to undisturbed montane forests. Identifying these ecological opportunity costs can enable land use management strategies to be worked out for entire regions.

4.7. In this study, for analytical convenience, Langdale-Brown's ecological classification was compressed into 10 zones. Of these ten zones most human settlements and agricultural activities in Uganda have been confined mainly to five zones (Plate IV):

-- the montane zone, with altitudes ranging from 2100 to 4500 meters on the eastern and western boundaries of the country;

-- the semi-deciduous and evergreen forest zone, extending in an approximately 80 kilometer arc around Lake Victoria;

Plate IV: Ecological Zones



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-- a woodland zone, where trees are shorter than in the forest zone, and the canopy less dense;

-- moist thicket zone, representing a transitional area to the Savanna;

-- the Savanna zone, covering most of northern Uganda.

4.8. Table 7 indicates the spatial impacts on ecological zones of land clearing for agriculture and livestock rearing in the 24 districts studied. The maximum pressure of settled agriculture on vegetation appears to have been in the forest and woodland zones. In the montane zone, except for the two districts around Mt Elgon, practically all other areas have still retained their forest cover, according to the 1986 LANDSAT image, and ground surveys (Hamilton 1984).

Table 7: Land Clearing for Agriculture by Ecological Zones (1986)

Ecological zone	Area cleared for Agriculture/livestock %	Coefficient of variation %	No of districts zone #
Montane	25	95	5
Forest	68	33	15
Woodland	73	40	16
Moist thicket	56	48	11
Savanna	50	56	16

Note: Most districts contain three or more zones

4.9. Land clearing in the forest zone has been actually practiced for several centuries in Southern Uganda. In a study of deforestation in Uganda, Hamilton (1984) points out that remaining forested areas around Lake Victoria are mostly secondary forests, growing on abandoned farmlands over the last century. These forests could regenerate, despite population pressure, because early in the twentieth century itself, the colonial administration had established a Forestry Department to safeguard their protection. Until the early 1970s this Department successfully protected forests around Lake Victoria, notably in Iganga and Mukono, despite acute population pressures on limited farmlands by the early sixties itself. In addition, the Department also administered large forest areas in the sparsely populated districts of Western and Northeast Uganda, (Hamilton 1984). Since the 1970s, as will be discussed later, the collapse of institutions has led to problems of widespread encroachments by farmers and charcoal producers in forested areas close to large human settlements.

Plate V: Changes in Land Use (from Agriculture)

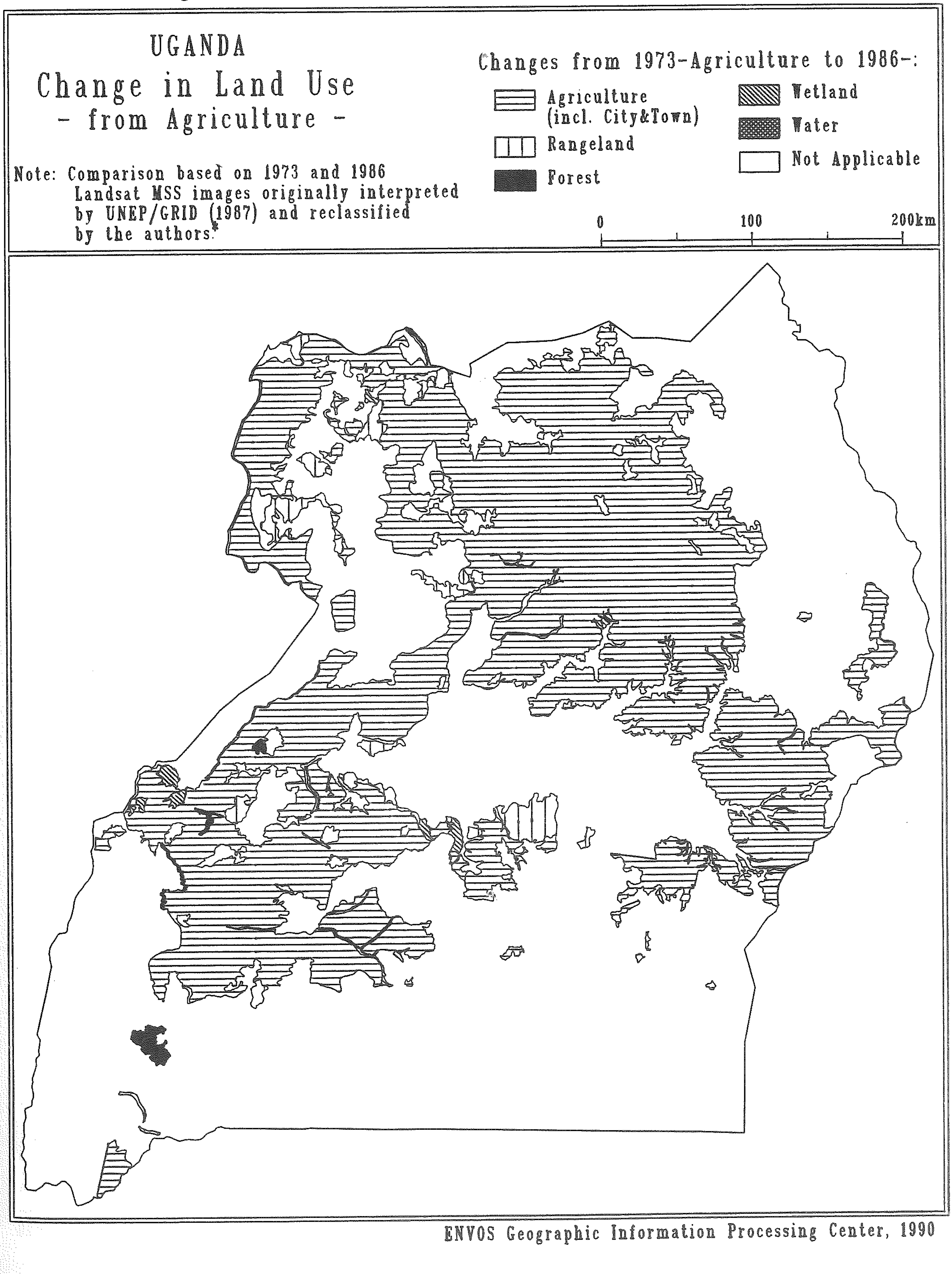

Plate VI: Changes in Land Use (to Agriculture)

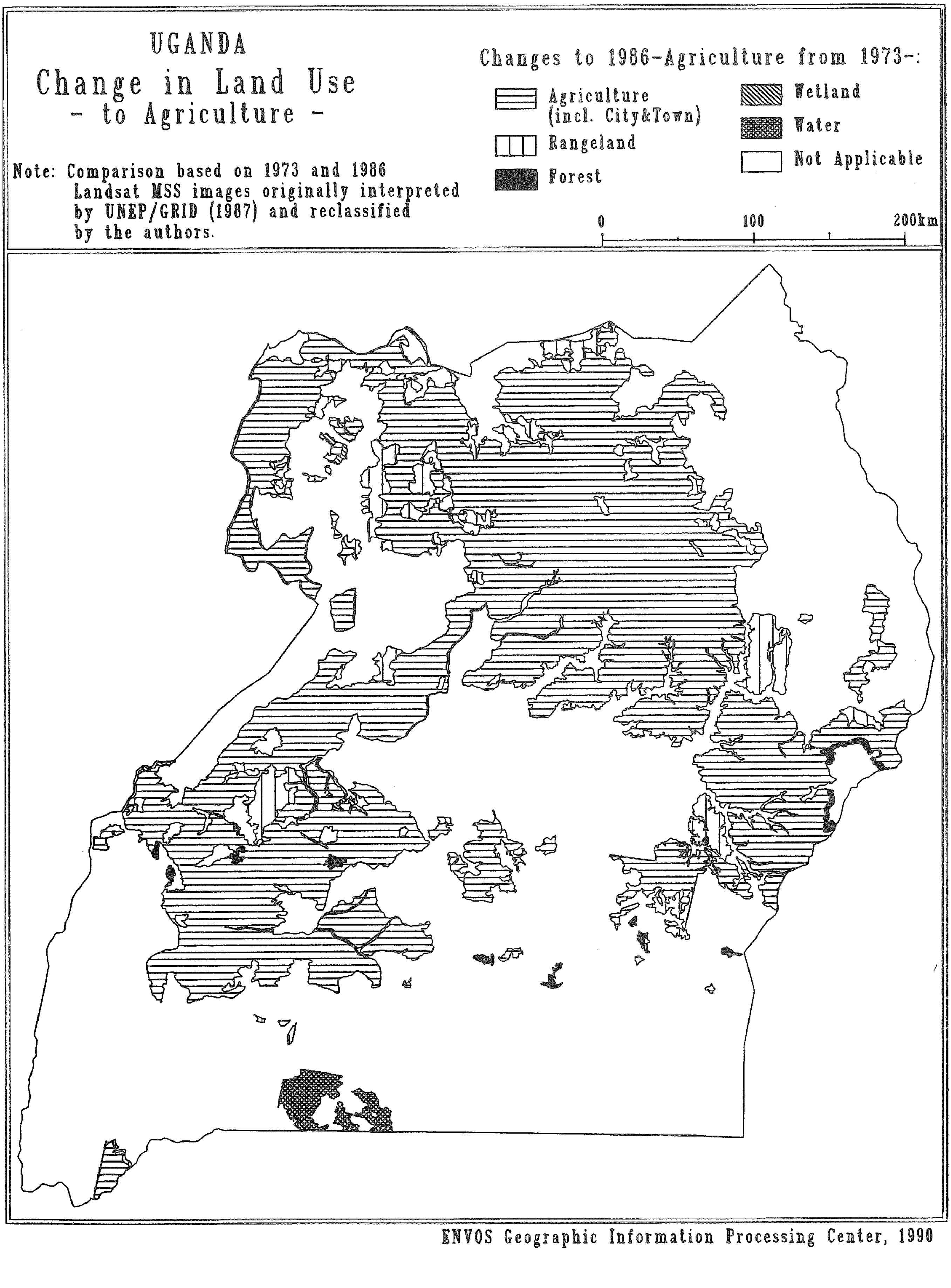

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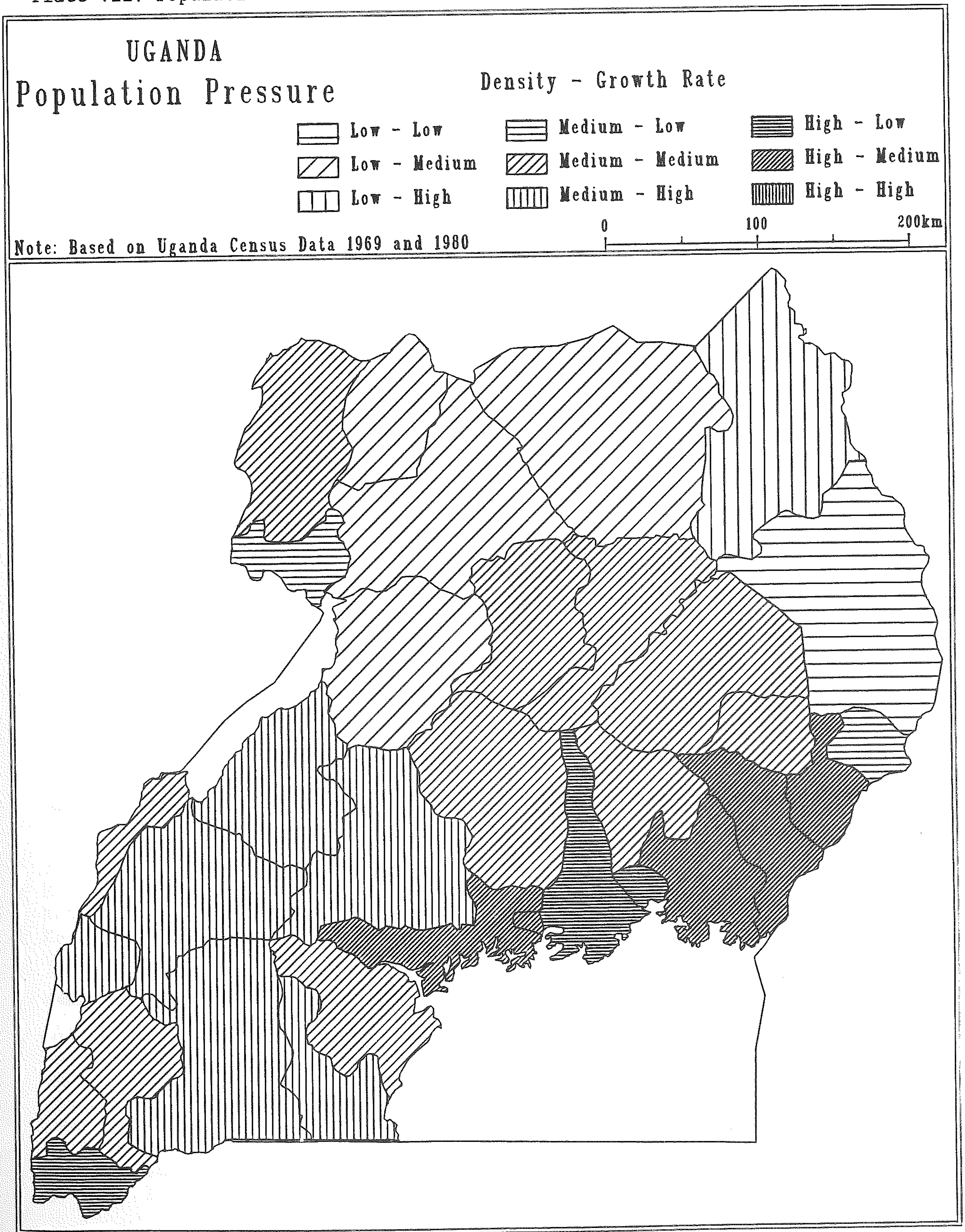
Plate VII: Population Pressure



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5. CHANGES IN AREA UNDER AGRICULTURE: A DIAGNOSTIC ANALYSIS

5.1. The aggregative analysis of the previous section has presented a mixed picture of land use in the study areas. While, quite expectedly, the pressure of land clearing appears to be the highest in the vegetative zones suitable for agriculture, land clearing increased significantly in the Savanna belt, and in the montane zone around Mt Elgon on the Kenya border. In this section a diagnostic analysis will examine the role of socio-economic factors such as population, infrastructure and economic policies in explaining the observed changes in land clearing between 1973 and 1986 (Plate V and Plate VI).

The role of population in explaining land use changes

5.2. Data from the 1980 Census was incorporated in the GIS, so that the impact of (a) population density; (b) rate of growth of population; and (c) urbanization could be examined in relation to land use changes (Plate VII). As the data could be disaggregated only to the district level, linkages between population pressure and natural resource use could not be tested for micro-regions.

Population density

5.3. Uganda's population distribution reflects large variations between the regions, and can for analytical convenience be divided into three groups. Districts along the Lake Victoria shore have population densities exceeding 100 per square kilometer. Karamoja and most of the northern Savanna districts have densities of less than 50 persons per square kilometer. In between, the middle group, extending from the Northwest to Eastern Uganda have densities between 50 and 100 persons per square kilometer.

Table 8: Population Density and Changes in Agricultural Areas by Three District Groups

Population density (per sq km)	Change in Agriculture	Change in vegetation areas
	----- % of total cloud-free area -----	
159 (excluding Iganga)	-0.5	-2.8
53	-8.7	+7.7
38	+5.0	-5.2
134 (Iganga)	+30.0	-31.8

5.4. Table 8 shows that there are no apparent causal relations between population density and changes in Agricultural areas. Districts with low population density in the Northern Savanna belt experienced more land clearing in absolute and relative terms, compared to more densely populated districts of Central and Southern Uganda. In the middle population density zone, there has been a marked increase in natural vegetative cover. Iganga was the only high population density district that witnessed a large-scale conversion of forests and woodlands to farming, for reasons explained below.

5.5. The low rate of agricultural expansion in most heavily populated districts is because hardly any natural vegetation is left for conversion into farmlands. Iganga was the only sample among the Lake Victoria districts that still had substantial forests protected by the Forest Department until the 1970s. With the institutional collapse of the last two decades, most of these forests became subjected to depredations from neighboring settlements (Hamilton 1984). At the same time, increases in vegetative cover does not imply that reforestation has taken place. As our analysis of the next section will show, the regrowth of bush very often took place in moist thicket and savanna zones, where the climax vegetative cover cannot support semi-deciduous or evergreen forests.

Rate of growth in population

5.6. Another equally relevant demographic variable is the impact of population growth on land clearing changes. The 1980 Census, confirming the trends visible in the 1969 Census, indicates a continued out-migration from the Northern Savanna areas to the relatively land-abundant Western districts of the country. Population growth rates in the densely populated Lake Victoria crescent area has been below the national average.

Table 9: Population Growth Rate and Land Use Changes

(a) 5 Districts with population growth rates above 4%

Name of district	Pop growth rate	Change in (i) agriculture	(ii)forest areas (Sq. kilometers)
	%		
Hoima	4.7	+63	-28
Kabarole	4.6	-332	+319
Mbarara	4.2	-82	+59
Kotido	4.2	-10	-26
Mbende	4.2	-475	+60
(b) Districts with population growth rate below 2%			
Gulu	1.8	+1381	-1379
Moroto	1.4	-12	-10
Moyo	1.6	-123	+273
Nebbi	1.3	-167	+126
Kapchorwa (Mt Elgon)	1.4	+310	-432

5.7. Overall, as Table 9 indicates, the relations between population growth rate and area clearance appears to be unconvincing at the district level. In areas above 4 per cent population growth, there has actually been a decline in land clearing, while the reverse has occurred in low growth districts. However, if one of the low growth districts (Gulu) is excluded from Table 9(b), virtually no change is noticeable. Similarly, Kapchorwa district, falling within the rapidly deforested Mt Elgon zone had one of the lowest increases in population growth. These findings require further field level verification because if more detailed demographic data had been available, the result might have been different.

Urbanization and changes in land use

5.8. The presence of large urban centers could have been an important factor explaining the clearance of natural vegetation cover, because of the proximity of markets for charcoal, poles for housing construction and fuelwood. Iganga, Mbale and Kapchorwa were three districts in proximity of Jinja and Mbale towns. These were also districts that witnessed rapid deforestation between 1973 and 1986. Overall, most districts in Uganda have less that 5 per cent of their populations residing in towns. Except for a few big towns in the south, and the vicinity of Kampala (unfortunately not included in this study because of cloud cover) and Jinja, urbanization is far less than in other comparable African countries. The information available did not permit us to draw more than a speculative conclusion.

Impact of roads on land use changes

5.9. Uganda had been reasonably well covered by a road network by the 1960s itself. In a growing economy, one can expect the road network to play a significant role in defining 'impact areas' where lower transport costs would encourage commercialization of farming. In Kenya, for example, the impact of rural access roads on land use patterns have been shown to be significant (Ecosystems 1982). In Uganda, the USAID (1984) survey indicated the location of most commercial activities along roadside, road junctions, apart from the settled trading centers. However, as discussed earlier, the period between 1973 and 1986 has witnessed a deterioration of the road and railway networks, and scarcity of transport vehicles.

5.10. An attempt was made to examine the impact of road networks. For sixteen districts that had comparable data on cloud-free areas, Figure 5 and Figure 6 show scatter plots of percentage change in agricultural area without and with roads, respectively, from 1973 to 1986. Changes in land use between 1973 and 1986 were not influenced by the road network (especially in the northern districts) because, for reasons discussed earlier, the transportation system had virtually collapsed.

Public policies and area changes

5.11. The analysis so far suggests that demographic factors and the road network by themselves are unable to provide a satisfactory diagnosis of what caused the changes in land use between 1973 and 1986. In this section the role of public policies is examined. In the case of Uganda, perhaps one has to consider the absence of public policies, and serious civil strife as the causal variables.

5.12. As discussed earlier, farmers in rural Uganda grew cash crops as income earning supplements to food crops. In some of the drought prone areas such as Gulu and Kitgum district, earnings from cash crops were also used to purchase food from the market in lean years, supplied by neighboring districts. Seers (1978), Barry and Hughes-Cromwick (1980) have classified districts in Uganda by agricultural or livelihood systems. This classification helps identify the major

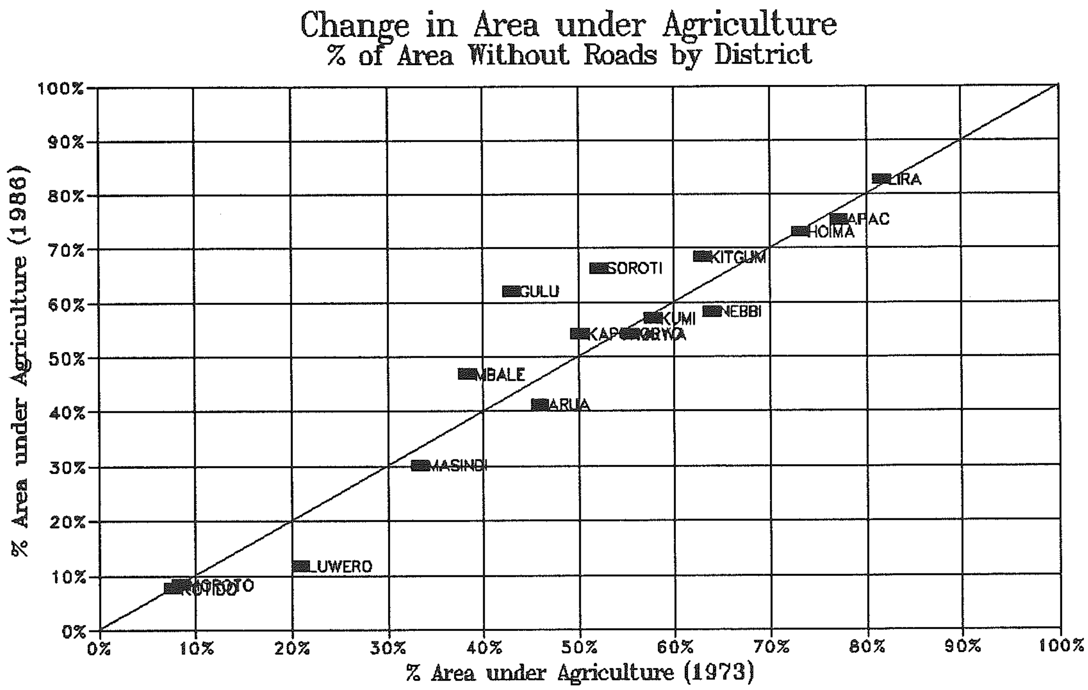


Figure 5

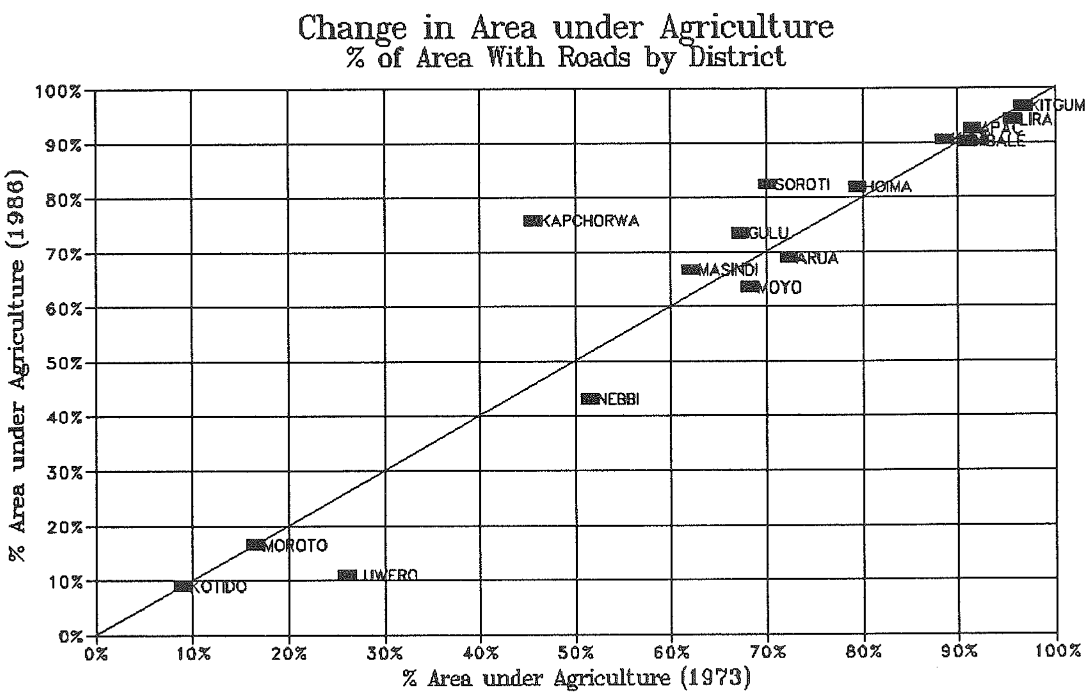


Figure 6

components of farmers' food security and cash income earning strategies by region (Plate VIII). The country can be divided into five broad livelihood systems, for which public policy instruments can be identified. These are:

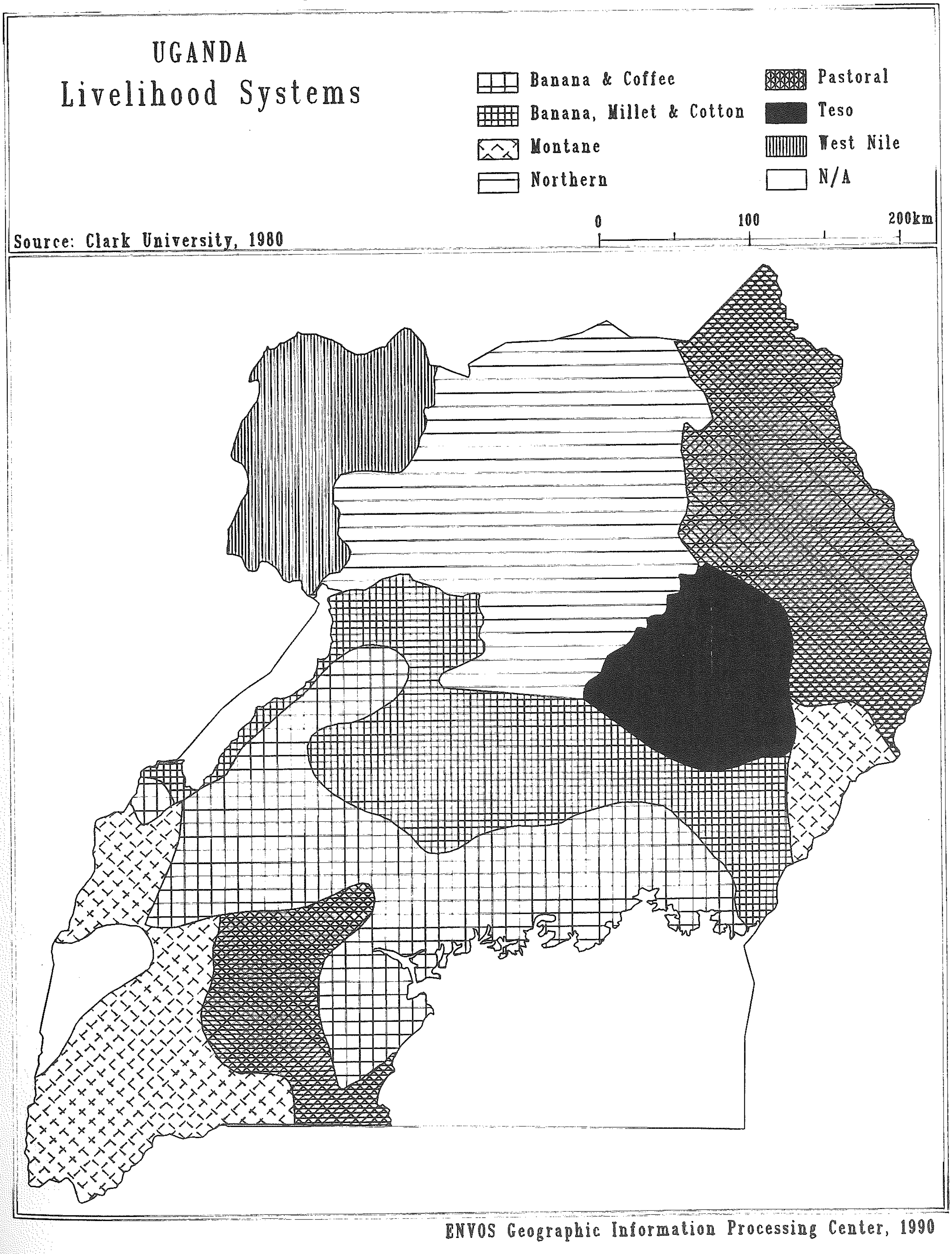
Livelihood system	Principal policy instrument
Banana and coffee zone	Coffee pricing policy, urban food prices, urban employment creation policies
Banana, millet and cotton zone	Cotton pricing, transport availability, Cotton ginnery policies
Montane zone	Arabica coffee, tea pricing, transport availability, Kenya pricing policies (Mt Elgon area)
Northern and pastoral zone (including Teso)	Cotton and tobacco pricing, transport availability, livestock husbandry, food security policies
West Nile zone	Tobacco pricing, transport availability fuelwood for curing tobacco

Table 10: Land Use Changes and Livelihood Systems

Zone	Change in (i) Agriculture % of total area	(ii) Vegetation	Total area sq kms
Banana-Millet-Cotton	-4.6	+3.2	32,324
West Nile (Tobacco)	-3.9	+6.0	14,905
Banana-Coffee (Without Iganga)	-2.8	+.8	23,303
(With Iganga)	+1.1	-3.0	26,400
Montane	+3.9	-.8	7,143
Northern	+8.4	-8.9	40,850

5.13. Table 10 summarizes the changes in land use by livelihood systems. In the Banana-Millet-Cotton and West Nile (tobacco) zones where the law and order problems were most acute (particularly in Arua, Nebbi, Luwero and Mubende districts), the decline in area under agriculture appears to be significant. In both these zones cash crop policy failures have also been reported (Seers 1979; USAID 1984). In the montane zone, declining farming areas in Western Uganda have been balanced by increased farming on the Mt Elgon slopes (bordering Kenya), where the arabica coffee area has increased in response to Kenyan coffee

Plate VIII: Livelihood Systems



prices. In the Banana-Coffee zone, if Iganga is excluded, a reduction in agricultural area is observable. With the inclusion of Iganga, a slight area increase has occurred between 1973 and 1986.

5.14. In the Northern zone, areas under the livelihood system are unable to explain large increases in land clearing in the districts of Gulu and Kitgum. In the third district of Soroti, competition between farming and livestock rearing may have caused the very large area cleared of vegetative cover. Although increases in pastoralism could have accounted for some of the observed land clearing, socio-economic factors are unable by themselves to explain the vegetative cover changes because: (a) a steady out-migration of labor had taken place from Gulu and Kitgum, (b) existing population density was relatively low, and (c) food insecurity was widely prevalent, indicating that farming had lost the dynamism exhibited in the 1960s. What has occurred can perhaps be better explained by non-economic factors; prolonged civil strife is reported to have devastated the district economies of Arua, Nebbi, Luwero, Mubende and Mpigi more than Kitgum and Gulu (Hansen and Twaddle 1988). Perhaps, the frequently recurring droughts since the mid-seventies was a major explanatory factor. More field level investigations are required to understand the causal factors leading to land clearing in these two districts.

6. ECOLOGICAL IMPLICATIONS OF LAND USE CHANGES

6.1. In this section, the capabilities of GIS to analyze the spatial impacts of economic activities are discussed. Eight districts of the country, which accounted for over 80 per cent of observed changes in vegetative cover are analyzed. Data bases on changes in land use (from Landsat images) and ecological zones (Plate IV), were combined together into n by m matrices for each of the districts. Two sample matrices, one for a district where a large area of vegetative cover was cleared (Iganga), and another experiencing re-vegetation (Luwero) are shown below.

Table 11: Land Use Changes by Ecological Zones

(Square kilometers)

(a) IGANGA	Agriculture	Range-land	Wet-land	Water	Total	Balance area(y)
Semi-deciduous forests (with roads)	-48	230	26	4	242	63
Semi-deciduous forests (without roads)	-8	298	4	-	294	20
Woodland (with roads)	-4	249	8	-	253	23
Woodland (without roads)	-	130	21	-	151	0
Total	-60	937	59	4	940	106

(b) LUWERO	Agriculture	Wet-land	Total	Balance area(y)
Evergreen forests (with roads)	-2	-	-2	0
Semi-deciduous forests (with roads)	-271	8	-263	25
Semi-deciduous forests (without roads)	-86	8	-74	15
Woodland (with roads)	-119	-	-119	143
Woodland (without roads)	-219	-	-219	45
Thicket (with roads)	-	-	-	1578
Thicket (without roads)	-227	6	-221	3589
Total	-924	22	-898	5395

6.2. The rows of the matrices describe the destinations of vegetative cover changes that occurred in terms of major climax vegetation categories. The columns indicate the origins of changes (i.e. land classification in the 1973 Landsat image). For example, the first entry of -48 for Iganga indicates that 48 square kilometers of cleared land in 1973 reverted back to its natural vegetation in 1986, and was located in the semi-deciduous forest zone within a road access area. The second row entry of 230 shows that 230 sq kms of rangeland (savannah, heath, bush, etc.) in 1973 was cleared by 1986, and so on. A negative number indicates a decrease in cleared area. The right lower total in the matrix represents the overall increase or decrease in vegetative cover in the district. A separate column (y) on the right represents the balance (non-cleared) area under a particular vegetation category. The totals of the first column and y represents the total area with vegetative cover in 1986.

6.3. By relating the first column (Agriculture) to column y, one gets an idea of the pressure of human settlements on ecological categories. In Iganga, for example, all ecological zones in column y appear to be under intense pressure from vegetation clearing activities: one could a priori infer that exhausted rotational fallow lands constitute the bulk of the first column total. In Luwero, the situation is somewhat different: while a comparable change appears to have occurred in the woodland and semi-deciduous forest zones, the moist thicket zone appears to have considerable stock of land under column y. Similar

Table 12: Ratio of Undisturbed Land Area to Re-Vegetated Land

Ecological zone	Ratio (column y:a1)	District	Livelihood system
Montane (without roads)	51	Kitgum (+)	Northern
Evergreen (with roads)	41	Kabarole (-)	Banana/Coffee
Evergreen (without roads)	49	,,	,,
Moist Thicket (without roads)	15.8	Luwero (-)	Banana-Millet-Cotton
	10.9	Mubende (-)	''
Savanna (with roads)	15.3	Gulu (+)	Northern
	14.3	Kitgum (+)	,,
Savanna (without roads)	143.4	Gulu (+)	,,
	30.5	Soroti (+)	,,
	23.3	Kitgum (+)	,,

Note: Positive and negative symbols denote overall increase or decrease in vegetative cover between 1973 and 1986 matrices for the other six districts have helped identify undisturbed natural vegetation cover in districts which may have experienced substantial changes in land use (Table 12).

6.4. Some interesting implications of the district-focused studies are:

* In both Iganga and Luwero, a substantial area where natural vegetation which had been cleared in 1973 reverted to bush by 1986. This feature appeared common in all other district-level matrices as well. The explanation, perhaps, lies in two factors. First, the rotational fallow farming system requires exhausted farmlands to be reverted to bush for re-generation. Although farmers are reported to have reduced the fallow periods because of the increasing scarcity of arable lands, in aggregative terms, the reversion of farmland to bush appears to have been substantial even in land-deficit districts like Iganga and Mpigi. Second, in districts like Luwero, where the re-vegetated area has been very substantial, large tracts of land devoted to cash crops and ranching probably reverted to bush, following the law and order problems, and a collapse of the market system.

* In districts where the re-vegetation occurred between 1973 and 1986, the first column (negative) total exceeds positive totals of other columns of the matrix, (as can be seen in the Luwero matrix). By contrast, in districts where overall land clearing has taken place, the total area in columns 2..n is greater than the negative total of the first column.

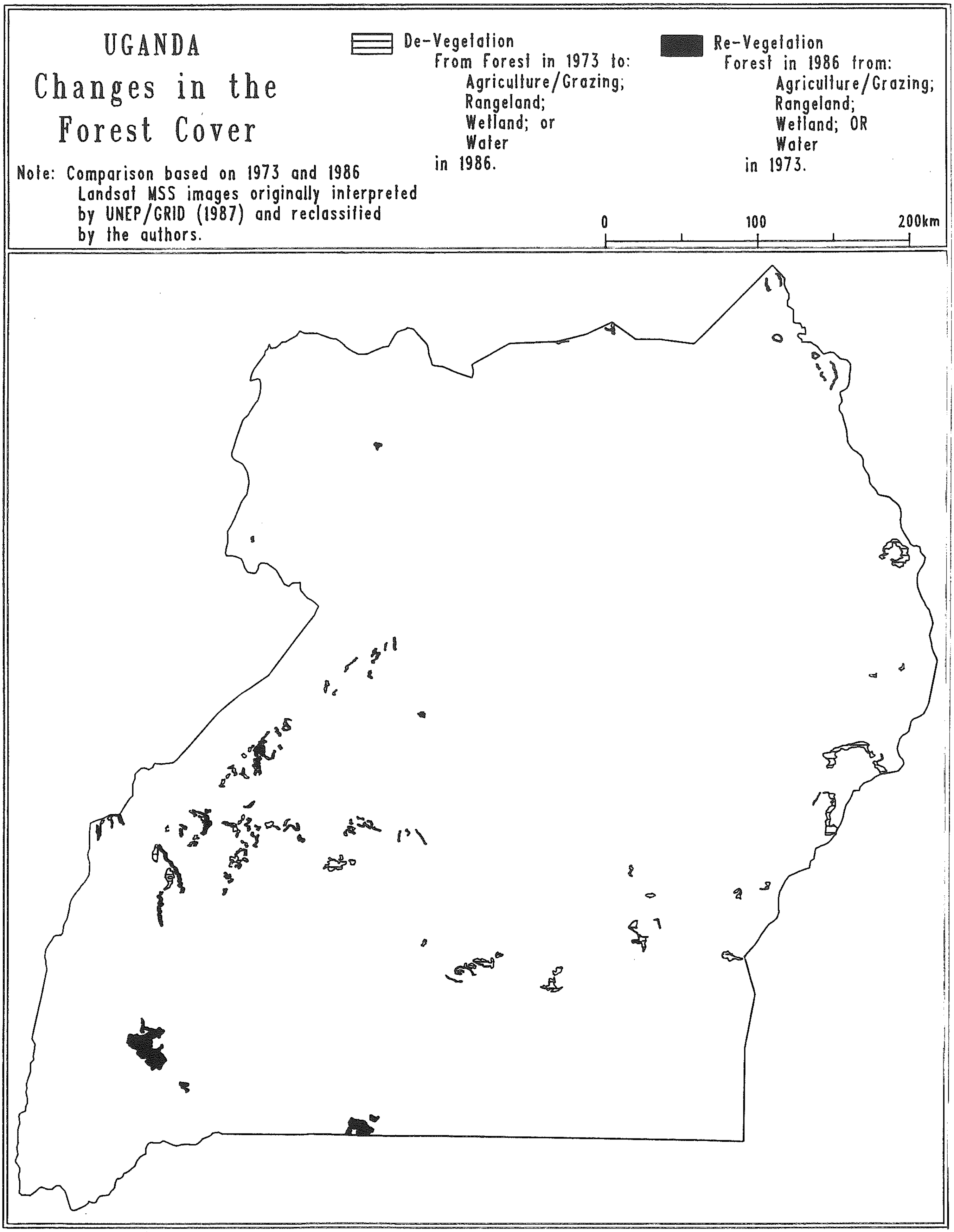
* Re-vegetated lands were mostly in the moist thicket and savanna zones, and not in the forest zone. This feature suggests that an increase in vegetative cover reported in many districts in 1986 does not dilute the problems of deforestation occurring in Uganda (Plate IX)

* In all districts, some wetlands or swamps were being brought into farming. The ecological implications of this feature needs to be further evaluated;

<u>Simulation Exercises</u>

6.5. The data sets can be used to generate "likely scenarios" of macroeconomic policies in terms of spatial impacts provided that conceptual linkages between various factors are identified. Also, this type of analysis requires linkages and economic variables to be expressed in a spatial format (see Section II). If, for example, the Government were to increase producer prices for tea to remunerative levels, the expansion of tea cultivation in a simple model would also depend on: (i) location of tea factories; (ii) road accessibility from tea producing areas; and (iii) tea growing area. As shown in Plate X, one can map out areas where combinations of these factors are present. By relating such areas to protected areas, areas of erosion risks, etc., the likely spatial impacts of policies to encourage tea cultivation can be evaluated.

Plate IX: Changes in the Forest Cover



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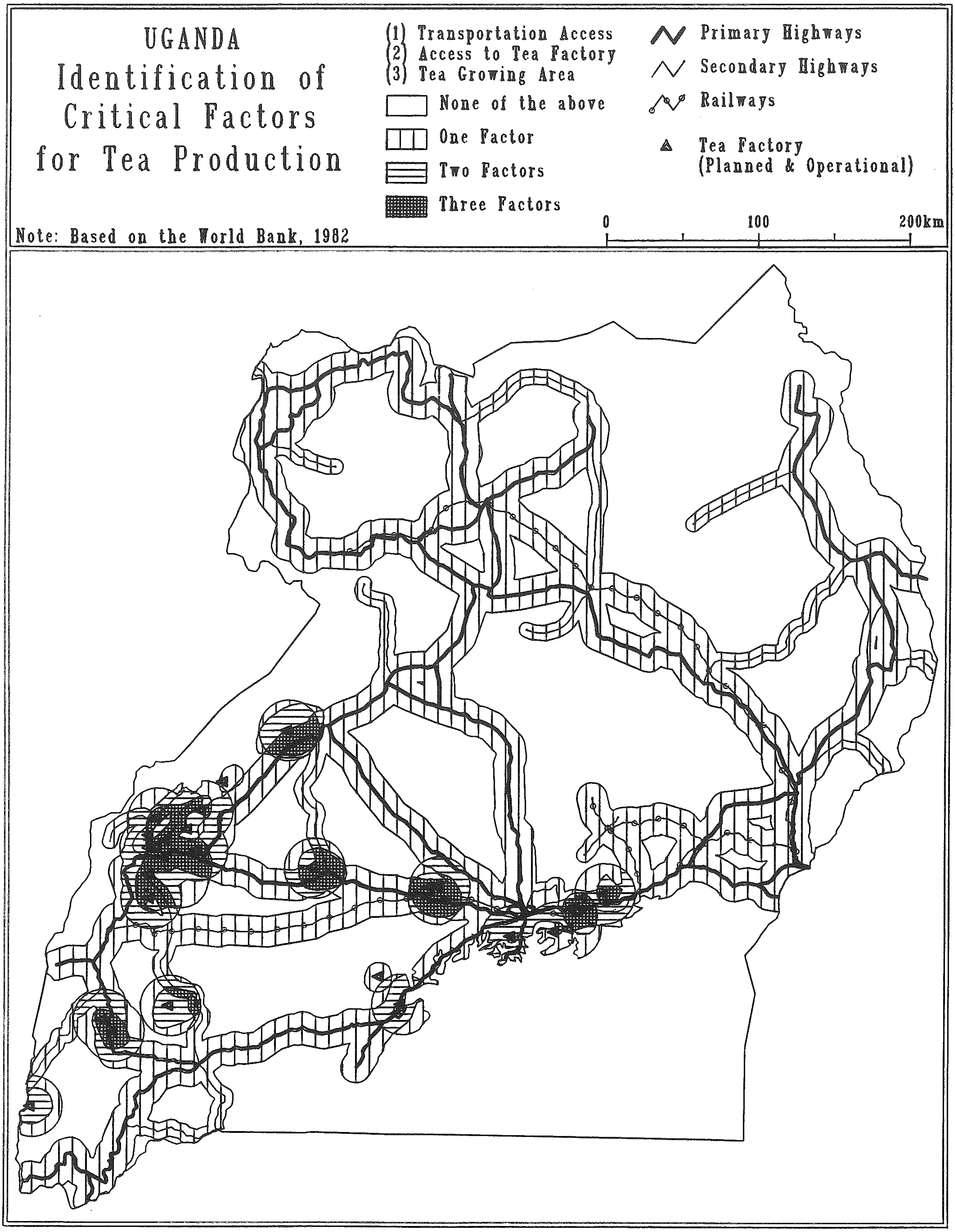
6.6. Following a similar procedure, spatial impact analyses for other pricing and investment decisions can be made. For example, improving incentives for cotton is likely to increase land clearing in several ecological zones: moist thicket (Luwero and Mubende), woodland and savanna (Gulu), savanna (Soroti). Each of these zones imposes a different set of opportunity costs on the ecological system in terms of soil erosion, devegetation impacts etc. Using the principle of comparative advantage, one could identify location-specific policies that would promote economic development that is sustainable in terms of environmental impact. These norms could help determine the discounted present value of protecting forest remnants in heavily populated districts like Iganga and Mukono, as well as undisturbed forests in the border districts.

6.7. The list of illustrations is demonstrative of what can be done using GIS, and is obviously not an exhaustive one. By combining temporal natural resources data and economic data sets in spatial context, it is possible to make regional-level assessments of renewable natural resource use changes.

Plate X: Identification of Critical Factors for Tea Production



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7. CONCLUSION

7.1. The object of this study on Uganda was to demonstrate that GIS loaded with temporal natural resources data together with even limited geo-based socio-economic data sets can serve an important function in evaluating the regional spatial impacts of public policies. The study has shown that despite the extremely complex nature of interactions between the physical environment and the economic system, most observed changes in vegetative cover over time can be attributed to human acts. As these human acts are often influenced by public policies, it is possible to trace land use changes directly to a set of economic pricing and investment policies. Specifically, in Uganda, the issues for further investigation raised by this study are:

* The lapses of public policies (because of political instability, deteriorating infrastructure and macroeconomic factors) have resulted in reduced farming areas in several districts because of declining incentives to produce cash crops;

* The importance of economic policies was equally visible (although in a perverse way) by the increases in coffee-growing areas on the slopes of Mount Elgon in eastern Uganda because of the high and stable Kenyan arabica coffee prices;

* The collapse of institutions seriously affected food security for Northern farmers and led to out-migration. In the southern districts, forested enclaves became exposed to rapid deforestation;

* Areas with rapid population growth rates found themselves already reaching the limits of the land carrying capacity. In the absence of improved farming technologies, the capacity of farmlands to meet food demand appear limited. This feature reduced fallow cycles, and in turn retarded the capacity of exhausted fallow lands to regenerate themselves;

* Population density and/or population rate of growth by themselves or together were unable to explain the observed changes in land use at the present level of analysis;

* Farming took place close to roads, although changes in land under agriculture could not be explained by access to roads.

7.2. To conclude, this pilot study of Uganda has attempted to demonstrate how Geographic Information Systems (GIS) can be put to use in a developing country, despite the several observable handicaps. Even in the absence of detailed data on socio-economic characteristics, the exercise has shown that GIS serves a very important role in diagnosing environmental problems at a regional and national level. The area statistics generated by overlaying different data bases can be put to a variety of uses, notably in the identification of ecological zones that are currently facing the maximum pressures from growing, poor human settlements. The somewhat crude method described in this paper can be refined to simulate spatial impacts of policies. In addition a detailed district-by-district profile of comparative advantages in natural resource use can help operationalize sustainable development priorities in these regions.

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