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Strategic Targeting of Development Policies to a Complex Region: A GIS-Based Stratification Applied to Uganda

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This paper proposes a GIS-based stratification procedure to provide spatially disaggregated information for targeting agricultural development policies. The developed approach was applied to Uganda under the research project “Policies for Improved Land Management in Uganda” (1999-2002). The main collaborating institutes of that project were International Food Policy Research Institute (IFPRI), Center for Development Research (ZEF), Makerere University Faculty of Agriculture (MUFA), National Agricultural Research Organization (NARO), and Agricultural Policy Secretariat (APSEC). We are grateful to the German Federal Ministry for Economic Co-Operation and Development (BMZ), the Norwegian Ministry of Foreign Affairs (MFA) and IFPRI for generous financial support. Special thanks go to Prof. P.L.G. Vlek, director at ZEF, for his scientific backstopping and his support to coordinate activities.

Abstract

It is often the case that national policies are not necessarily suitable at lower administrative levels due to the spatial complexity of natural and socio-economic resources within a country. That complexity of resources can be resolved by spatial modeling of natural and socio-economic variation. We propose a new GIS-based stratification algorithm to demarcate homogenous development domains at national level and applied that algorithm to Uganda. Based on that stratification, we assembled various spatial information to assess comparative advantages and disadvantages of these development domains for potential pathways of economic development. We expect that our stratification strategy may help policy makers and regional planners to target development investments more efficiently towards sustainable agriculture in Uganda.

Kurzfassung

Es ist häufig der Fall, daß Politikempfehlungen auf nationaler Ebene nicht direkt auf tieferen Verwaltungsebenen anwendbar sind, da Standortfaktoren wie z.B. natürliche Ressourcen und sozio-ökonomische Bedingungen in einem Land räumlich sehr heterogen sind. Diese Heterogenität der Standortfaktoren kann mittels räumlicher Modellierung aufgelöst werden. Wir stellen einen neuen GIS-basierten Stratifizierungsalgorithmus vor, um unter expliziter Berücksichtigung der räumlich variablen Standortfaktoren homogene Entwicklungsgebiete („development domains") abzugrenzen. Diesen Algorithmus wendeten wir auf Uganda an. Auf Grundlage unserer Stratifizierung stellten wir räumliche Informationen zusammen, um die Vor- und Nachteile jener Entwicklungsgebiete für zukünftige wirtschaftliche Entwicklungen zu beurteilen. Wir gehen davon aus, daß die Anwendung unserer räumlichen Stratifizierungsstrategie Politikern und Regionalplanern helfen kann, Entwicklungsinvestitionen präziser und effizienter für eine nachhaltige Landwirtschaft in Uganda einzusetzen.

1 Introduction

Land resources are crucial assets for many developing countries in which agriculture is the economic backbone. Rapid population growth and unfavorable socio-economic conditions in many developing countries have been putting great pressure on their natural resource endowment. This results in continuous land degradation and crop yield decline, which has been particularly severe in many sub-Sahara African countries (Stoorvogel and Smaling 1990). Although Uganda was once considered to be one of the most ‘fertile’ regions in Africa (Cheney, 1960), that image has meanwhile changed to the opposite. Stoorvogel and Smaling (1990) estimated that soil nutrient losses in Uganda were one of the highest among African countries in the early 1980s. Wortmann and Kaizzi (1998) reported large negative nutrient balances for most cropping systems in central and eastern Uganda. Such land degradation patterns are most likely connected to low agricultural productivity and poverty, which again increase pressure on land resources (Sserunkuuma et al., 2001).

In January 1999, the International Food Policy Research Institute (IFPRI) initiated a new research project, called “Policies for Improved Land Management in Uganda”. The collaborating institutions were the Makerere University Faculty of Agriculture, the National Agricultural Research Organization, the Agricultural Policy Secretariat, and the Center for Development Research. The main goal of this project was to contribute to improved land management in Uganda, in order to increase agricultural productivity, reduce poverty and ensure sustainable use of natural resources (IFPRI, 1998). The direct purpose was to help policy makers identify and assess policy, institutional and technological strategies to improve Uganda’s land management.

It is widely accepted among policy makers that blanket development strategies, which are applied at national level, may not necessarily be suitable at lower administrative level (Pender, 1999). One of the fundamental stumbling blocks for more effective policy dissemination is the spatial complexity of biophysical and socio-economic conditions at different spatial scales. Considering the whole territory of Uganda, natural resources including climate, soils, topography and vegetation are highly diverse. The same spatial variability occurs for socio-economic factors, such as population pressure, market access or land tenure system. It becomes clear that policy strategies can only be successful if they strengthen the specific potentials and relax the particular constraints of natural resources and socio-economic conditions for certain agricultural activities in a target region.

Effective policy recommendation and its implementation require an understanding of the spatial distribution of natural resources and socio-economic conditions. This will support policy makers, identify and assess the opportunities and constraints of a specific area for certain agricultural activities in order to make sound decisions which policy, institutional or land management strategies are best suited (Carter, 1997; Wood et al., 1998). Any attempts to implement such site-specific strategies at national level require at first to define a spatial boundary around the target system in which complexity of individual system components is reasonably similar (Kam and Oberthuer, 1996; Bourgeron et al., 2001). Notwithstanding numerous conceptual discussions on site-specific development strategies, there is no standard approach for such delineation procedures. This is mainly because of the extreme spatial diversity of both natural resource and socio-economic factors that are interacting with each other.

The objective of this discussion paper is to present a GIS-based stratification approach to demarcate spatial domains that are homogenous in terms of dominant agricultural factors and processes in Uganda. Based on the stratification results developed in this paper, a spatial sampling framework was established to select 108 communities that were representative for development domains covering Central, East and South Uganda. Intensive natural resource mapping and socio-economic surveys were carried out in those communities during the year 2000 and 2001 (Pender et al., 2001, Ruecker et al., 2003). The objective of those field investigations was to identify potential policy, institutional and technological strategies to improve the sustainability of agricultural development in Uganda. Some initial results have been already published elsewhere (Pender et al. 2001).

This paper consists of three main chapters: 1) the methodological framework to characterize spatial domains of natural resources and socio-economic conditions (Chapter 3); 2) the GIS-based stratification algorithm that was applied to the whole territory of Uganda based on pathways of development theory (Chapter 4), and 3) the discussion on comparative advantages and disadvantages of each domain for targeting potential policy, institutional and technological strategies (Chapter 5).

2 Setting

Uganda is located astride the Equator in East-Africa. It stretches from approximately 4°12′ N to 1°29′ S and 29°34′ W and 35° 0′ E. Sudan borders on Uganda in the north, Republic Congo in the west, Rwanda in the south-west, Tanzania in the south and Kenya in the east. The total area of Uganda is approximately 230,000 km^2. However, the land surface covers only 179,400 km^2, as open water resources such as the Lake Victoria take about 18% of the country (Harrop, 1970).

The population of Uganda is over 21 million and rapidly growing at an annual rate exceeding 2.5%. More than 80% of the total population are engaged in agriculture which comprises a large variety of both crop and livestock products. Agriculture forms the backbone of the economy and contributes over 55% to the GDP and over 95% to the export revenue. Until 1997 coffee exports made 50% of the total exports of goods, besides tea, cotton and tobacco. However, in recent years non-traditional export crops became more dominant and products such as simsim, beans, maize and soya beans have been increasingly exported (Gakwandi, 1999 and National Environment Management Authority, 2001).

Although Uganda has relatively good agro-climatic resources for agriculture, many farmers lack the means and knowledge to apply appropriate land management. This has contributed to relatively poor crop productivity, which Walaga et al. (2000) have classified to be among the lowest in the world. To maintain reasonable crop yields, agronomists promoted soil and water conservation as the most suitable land husbandry practice up to the 1950s. Subsequent research indicated the importance of fallow management, use of crop rotations, improved fallows, green manures and inputs as well as integrated nutrient management (INM) during the cropping phase to improve soil productivity (Ssali, 2000 and 2001).

During the fallow period soil physical properties improve and leached nutrients are recycled. Per capita arable land in Uganda has decreased from 5.2 ha in 1931, to 1.9 ha in 1969 and 0.8 ha in 2000 (National Environment Management Authority, 2001). Hence as population pressure has increased fewer farmers can afford to rest the land. Although improved soil management practices have been found to increase crop yields on fields, very few farmers have adopted them. Instead, the majority of farmers continue to employ low technology to manage natural resources. As a consequence the yield gap between crop yields produced by researchers and yields achieved by farmers remains high. Yields range for example for maize grain from 1.2 to 2.1 t ha^{-1} for low potential and from 1.5 to 3.3 t ha^{-1} for high potential soils in Eastern Uganda above that of farmers′ yield (Kaizzi, 2002).

In the 1990s agricultural researchers in Uganda started to study methods of increasing agricultural productivity by using available nutrient resources more efficiently, while safeguarding the environment for future generations. These integrated nutrient management methods incorporate usage of both organic and inorganic plant nutrients to attain higher crop productivity and to prevent soil degradation (Wortmann and Kaizzi, 1998; De Jager et al., 1999). Successful INM requires first to assess the spatially variable natural and socio-economic resource conditions of an area such as agricultural potential, population density and market access for possible fertilizer strategies. Based on that assessment, site-specific INM can then be developed, which are targeted to both the ecological and socio-economic needs of a certain land, its people and markets. The present challenge is therefore to generate spatial information that could assist policy makers to recommend site-specific land management policies, technologies and institutional strategies that are targeted to the spatially variable natural resource socio-economic conditions.

3 Capturing Spatial Variability

One of the fundamental constraints for a more widespread adoption of development policies at national level is the huge complexity of the natural resource and socio-economic system at lower level. Concerning the natural resource system, energy and matter (e.g. water, nutrients, carbon) are continuously exchanging between earth's surface system boundaries. That system consists again of numerous individual system components (e.g. agricultural fields) with complex interactions among them (e.g. by nutrient flows) (Mauser, et al., 2001).

Spatial heterogeneity and interaction is also the case for the socio-economic system. Individual social and economic activities vary widely depending on environmental opportunities and constraints, educational background and cultural as well as social structure. Spatial variability of peoples´ socio-economic behavior is further complicated by human's adaptive nature, social interactions, and different individual needs. One can for example observe neighboring households within a community having markedly different socio-economic circumstances and pursuing different land use enterprises hence might have different development objectives. Further complexity occurs due to human's migrant nature. People who are dissatisfied with their environment or who search for better job opportunities frequently move to other places. Since human actions show strong lateral connections, very often the exact system boundary does not exist or is arbitrarily chosen for socio-economic factors.

Such complexity inevitably forces scientists and policy makers to investigate the 'average' condition of natural and socio-economic systems, while they frequently ignore the variance characteristics (Carter et al., 1997). Spatial variation has long been considered as a complicating factor for traditional agronomic research. The only way to take account of such variability was to increase the number of trials in order to remove 'noise' and 'error' associated with spatial variation. This is also true for traditional agro-economic analysis. Mainstream economic models prefer building a model as a tool for policy decision support. These models aim to derive general 'trend' and 'functions' from data, ignoring variance characteristics of information at certain spatial scales. If spatial variability of agro-ecosystems would be considered, enormous complexity would inevitably be introduced to model structure and interpretation of model performance (Beven and Kirkby, 1979). On the other hand, spatial information scientists have a rather opposite perspective on spatial variation. Space has been perceived by them as an opportunity to integrate interactions among phenomena. Therefore, the explicit study of spatial variation can be considered as a promising strategy to better understand and to take account of these interrelationships (Carter et al., 1997). This spatial research branch is now becoming one of the main priorities in current resource management studies and policy recommendations.

3.1 Integration of Spatially Variable Natural Resource and Socio-Economic Factors

In recent years, the application of modern geographic information technology to spatial data has evolved to the top research methodology in developing site-specific policies and land management strategies (Dumanski and Craswell, 1998; Wood and Pardey, 1998). Geographical Information Systems (GIS) can be defined as a set of computer tools for collecting, storing, retrieving, transforming and displaying spatial information from the real world (Burrough and McDonnell, 1990). GIS has been particularly useful for visualizing, querying and analyzing spatial patterns of various geographical phenomena. New possibilities have been arising as GIS is getting tightly coupled with remote sensing, spatial statistics, and spatial simulation models. Supplementing application-oriented aspects such as spatial analysis to identify policy options, GIS can be characterized as a decision support system involving the integration of spatially referenced data in a problem solving and planning environment at different spatial scales (Kenneweg, 1992; Cowen, 1988).

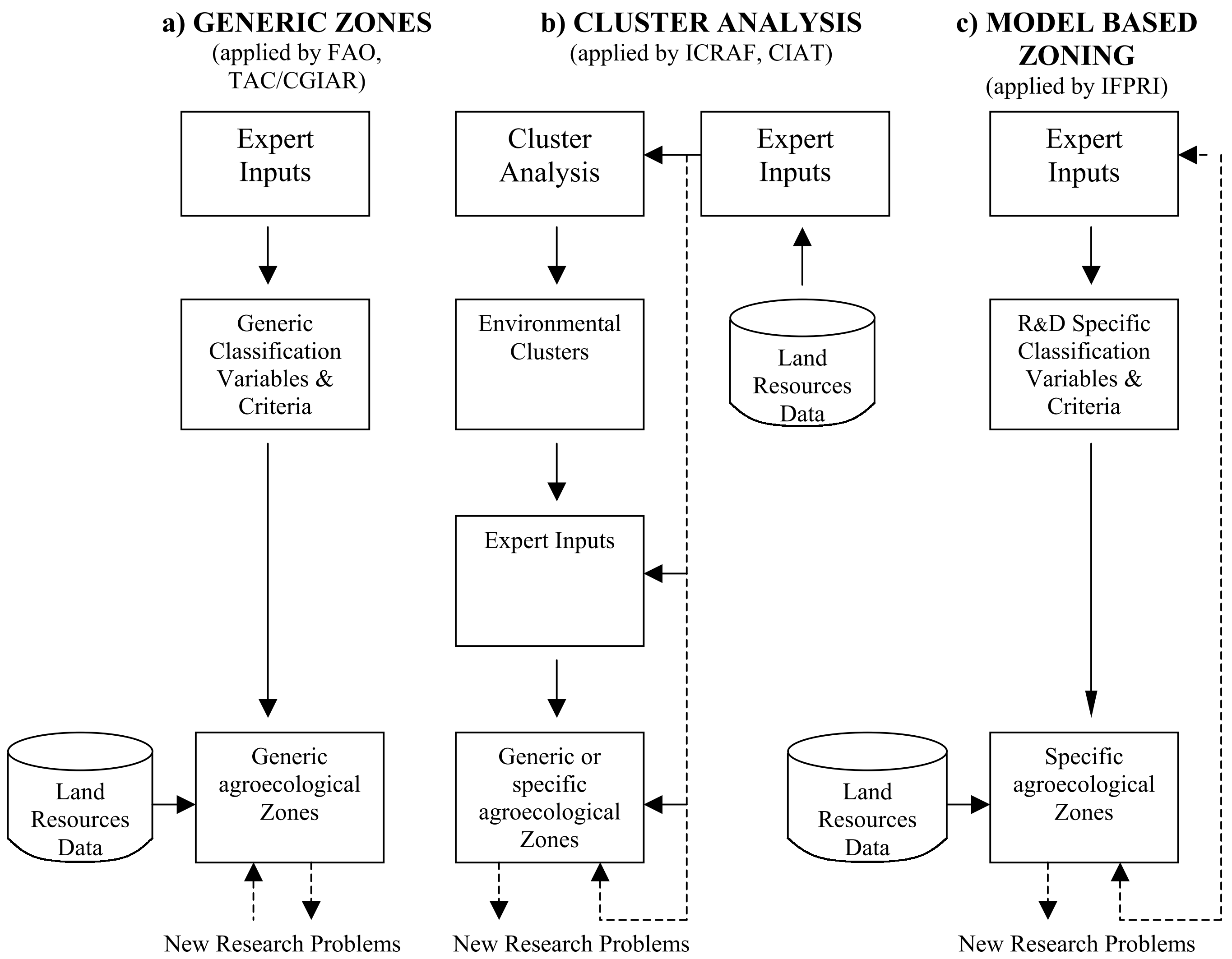
Notwithstanding its overall potential and rapid technological development some critical issues remain unsolved and require further attention. One of the main problems is how to integrate natural resource data with socio-economic data to analyze complex agricultural regions for targeting policy and land management strategies. Elements in a natural and socio-economic system respond nonlinearly at different spatial scales, according to different thresholds and lags, and with varying degrees of feedback (Becker and Braun, 1999). Even though the climatic and hydrological processes may be the same for a specific area, many variables might show entirely different spatial variance characteristics, if considered at a different spatial scale (Park and Vlek, 2002). This raises the question how to model the complex interactions among various natural and socio-economic process components for certain spatial domains. In a development context, questions might come up to policy makers such as: How does soil quality interact with farmers´ decisions to recommend the best-suited land management technology for a certain site? How do farmers´ specific socio-economic conditions influence land management decisions? Similarly, where do soil quality and agro-climatic conditions interact with each other for determining best crop yield? Conventional spatial analyses have mainly dealt with one or more of those issues in an isolated manner, but the identification of spatial units based on problem issues and the resource base has been rarely analyzed in an integrated and interactive manner (Dumanski and Craswell, 1998).

One possible way to capture such complex interactions is to isolate the most significant system elements that explain both the signal and the variance in the response. Those system elements can then be used to stratify the whole area into homogenous spatial domains. At meso- or macro scale seasonal rainfall distribution may strongly govern farming systems (e.g. annual cropping versus perennial cropping system) and can be applied to stratify domains of different agro-climatic potential. Accessibility of markets and condition of road networks in a rural area might have a strong impact on a farmer's decision which specific cash crops might be most profitable to cultivate, even with unsuitable climate and soil conditions prevailing in that same area. Although internal variability might be strong within each domain, the identification of dominant factors that determine the major components of total variance of an agro-ecosystem is one possible stratification strategy to reduce spatial variability.

3.2 Spatial Stratification Strategies

Spatial stratification strategies have been used in many conceptual approaches at national and continental scale to integrate natural resource and socio-economic variables into homogenous spatial stratification units. In current literature, different procedures for spatial stratification are reported that are applied in agricultural policy research. Wood and Pardey (1998) grouped them into three categories: 1) generic stratification, 2) clustering approach, and 3) model-based stratification (Figure 1).

Figure 1: Approaches to Stratify Spatial Data and Related Processes (Wood, 1998)



Generic stratification uses a general and broadly defined set of ecological and socio-economic variables to demarcate homogenous areas in terms of major production systems and natural-resource degradation hazards (Figure 1 (a)). An example for the application of generic stratification at global scale is the agro-ecological zones (AEZ) project (FAO, 1996). The TAC/CGIAR further generalized FAO´s AEZ at continental scale and used two derived climate variables, one based on temperature and another one on moisture availability to delineate homogenous ecoregions (Gryseels et al., 1992). Generic stratification was mainly applied for coarse stratifications to suit a large range of potentially researchable topics at broad scale. However, application of that broad concept are rare, if specific research agendas and spatial variations at a more detailed scale, such as at nation level, need to be investigated.

In the clustering approach, selected natural and socio-economic variables are statistically grouped together in order to reduce the dimensionality of the system (Figure 1 (b)). There are many different types of clustering methods (Gauch, 1982; Estivill-Castro, 2002). In all of these approaches, the objective is to classify a sample of entities into a smaller number of exclusive groups (clusters) based on the multivariate similarities among entities. Due to the subjectivity used for clustering procedures, it is generally recommended to replicate the analysis under varying conditions (Everitt, 1977). Batjes (2002) used for example the different soil variables to cluster the soil horizon data of over 9600 soil profiles held in the World Inventory of Soil Emission Potential (WISE) database. The generated clusters and derived soil chemical and physical attributes are appropriate for use in studies from regional to global scale. Cluster analysis was also employed by Kelley et al. (1997) to generate spatial rainfed agriculture sub-divisions for the whole area of India. He integrated various data on crop production and socio-economic factors. Those cluster analysis applications show, as in generic classification, that these kind of stratification approaches are mainly used in broad scale studies, where the objective is to delineate zones that are suitable for a wide range of potential research. However, if more site-specific scientific research is required, a different stratification approach needs to be chosen, which is more accurately designed to the spatial variability of resources and tightly coupled to the specific research agenda (Batjes, 2002).

The model-based stratification is an approach in which carefully selected natural resource and socio-economic variables that characterize the specific agro-ecosystem processes of interest within a study region are systematically combined to demarcate spatial domains (Figure 1 (c)). The selection and combination of variables require comprehensive ex-ante assessment of the processes of the target region and is often based on a conceptual model. That approach was for example used by the International Service for National Agricultural Research (ISNAR) and by the International Food Policy Research Institute (IFPRI) in several country-level research studies (Pardey and Wood, 1994). In a study in Burkina Faso, Wood et al. (1999) demarcated for example different domains of agricultural potential by model-based stratification using satellite data of NOAA´s Advanced Very High Resolution Radiometer (AVHRR) from 1981 to 1991. In that study they combined average normalized difference vegetation index (NDVI) and its interannual variability by GIS-based intersections. The NDVI-based agricultural potential was chosen, since it represents site-specific and integrated responses of climate and soil processes. Further applications of that approach were for example performed for Uganda, Kenya and Ethiopia (Ibid.). This model-based stratification is very flexible, because criteria, number and boundary conditions of the stratification domains are developed only for a specific target-area based on ex-ante assessments (Pardey and Wood, 1994). Although it has been mainly applied in national level studies, it is suited also for more detailed resolution agricultural resource stratification, where specific agro-ecosystem processes will be studied. However, that specific model-based procedure makes direct comparisons of stratification results from several study regions with contrasting processes difficult, because of the different applied models.

All these methods are not exclusive of each other; instead approaches should be combined to identify possible interactions. The stratification procedure should be interactive and easy to be updated. Considering the limited knowledge on natural resource and socio-economic interactions, it is virtually impossible to build a ‘perfect’ stratification system. However, the general stratification procedure should be open to public discussion and continuously improved by means of field observation and integration of local experts´ knowledge.

4 GIS-Based Stratification of Uganda

Based on the methodological discussions, we developed a model-based stratification approach to reduce total variability of natural and socio-economic factors related to agricultural development over the whole territory of Uganda. Considering the wide spatial coverage and associated complexity of the different agricultural conditions and processes on the one hand and the currently available small scale national level GIS data on the other hand, a national level stratification is prone to conceptual and generalization errors, thus leaves room for further model refinement. However, the objective is to demarcate the whole territory of Uganda into several homogenous spatial domains where the spatial distribution of natural and socio-economic factors are relatively similar within each domain by using available data. The new spatial information that is generated by stratification will be an important source of knowledge for policy makers to formulate site-specific hypotheses about natural resource and socio-economic factors and processes that influence agricultural development within spatial domains. These spatial domains provide the reference units to determine the comparative advantages or disadvantages of a certain region, which in turn assists policy makers to better identify and target policies and improved land management technologies to certain geographic domains.

4.1 Conceptual Model: Development Pathways

Natural resource and socio-economic factors that are characteristic for a particular region can be spatially integrated by using a conceptual model. Based on such as conceptual model characteristic factors of a region can be stratified into spatial domains with different advantages or disadvantages for certain agricultural activities. The model for the proposed stratification procedure is the ”development pathway” concept (Pender et al., 1999). A “development pathway” is defined as a common pattern of change in farmers´ livelihood strategies, associated with its causal and conditioning factors (Ibid.). If for example the conditioning factors such as good market access, high agricultural potential and high population density are gaining dominance in a certain area, farmers might intensify cash crop production as the pathway of development, which might lead to highest returns of investment. Another example with exactly opposite factor values might be characteristic for an area with low market access, low agricultural potential and low population density. Farmers in that area with low factor values might follow the development pathway of food production extensification in order to make best use of given resources (Pender et al., 1999).

Many natural and socio-economic factors may determine development pathways depending on the specific study location. Based on previous research on agricultural development, some natural resource and socio-economic factors were found to be of particular importance. Pender et al. (1998) suggest four main factors that are particularly important in African conditions, including population density, access to markets, agricultural potential and altitude (cited by Wood et al., 1999).

1) Population density impacts on labor intensity of agriculture by affecting the land/labor ratio, and may also induce innovations in technology, markets and institutions, or investments in infrastructure. Population pressure in turn affects the comparative advantage of labor-intensive pathways of development, as well as returns to various types of investments.

2) Access to markets is critical to determine the comparative advantage of a certain location, given its production potential for agricultural products. For example, a community with an absolute advantage in producing perishable crops may have little or no comparative advantage in perishable crop production if the production site is located far from roads and urban markets. Market access is a multi-dimensional and dynamic concept and can include for example factors such as distance and condition of roads, distance to urban centers, access to transport facilities, access to international markets, etc.

3) Agricultural potential is also an abstraction of many factors – including rainfall amount and distribution, soil type and depth, presence of pests and diseases, presence of irrigation, and others – that influence the absolute (as opposed to comparative) advantage to generate agricultural products in a particular place. There are of course variations in the potential depending upon which commodities or livestock products are being considered. Furthermore, agricultural potential is also a dynamic concept that changes over time in response to changing natural conditions (e.g. climate change) as well as human-induced conditions (e.g. land degradation).

4) Altitude has a major influence on agro-climatic, soil, and crop management in mountainous regions. Elevation and topography affects rainfall distribution, soil erosion processes and growing cycle of crops. Therefore, if a study region incorporates both highland and lowland areas, elevation may be explicitly considered in order to take those specific processes in highland regions into account.

Those four factors can then be combined together to demarcate “development domains” within a target region. Based on the comparative advantages and disadvantages of development domains, possible development pathways can then be identified. Furthermore, policy makers may decide to promote particular pathways of development to strengthen those factors leading to a comparative advantage within an area (e.g. intensification of perennial cash crops in areas with high agricultural potential, high population density and high market access). Alternatively policy makers may propose strategies to diminish factors that are constraints in a possible pathway of development (e.g. promoting extension services that train farmers in landscape-specific soil and water conservation management to reduce soil loss along hillsides).

4.2 Spatial Stratification of Development Domains in Uganda

The spatial scale of the stratification study covers the total area of Uganda. Although several national as well as international institutions collect digital data sets for different areas of Uganda, only few institutions have them available at national scale (Guillaume and Lambotte, 1998; National Environmental Management Authority, 2001). Table 1 shows the GIS layers used in the stratification procedure[1].

Table 1: GIS Data Description and Sources Used in the Stratification

Spatial domain	Scale	Source	Remarks
Population density	"Parish" (corresponding to one local administrative unit above community)	GIS-parish boundaries: Ministry of Natural Resources, Department of Forestry, Uganda, (1999); Population data: Ministry of Finance and Economic Planning - Statistics Department- Cartography Unit (1997)	Population data from the latest available national census (1991)
Market access	5 x 5 km raster	World Resource Institute (WRI) (1999)	Algorithm after Deichmann (1997)
Agricultural potential	5 x 5 km raster	Corbett and O´ Brien (1997) Corbett and Kruska (1994)	Average data from long term monthly mean climatic records
Elevation	1 x 1 km raster	Hutchinson et al. (1995)	Digitized data from air navigation charts and maps at larger scales; ANUDEM algorithm to construct DEM (Hutchinson 1989)

[1] All layers were integrated under the same coordinate system (Grid UTM Zone 36, Projection: Transverse Mercator, Spheroid: Clarke 1880 (Modified), Datum: New (1950) Arc) at the administrative level of parishes. All digital data sets were stored in the Geographical Information System ARC / VIEW 3.2® (Environmental Systems Research Institute, Inc.,1999a).

4.2.1 Population Density

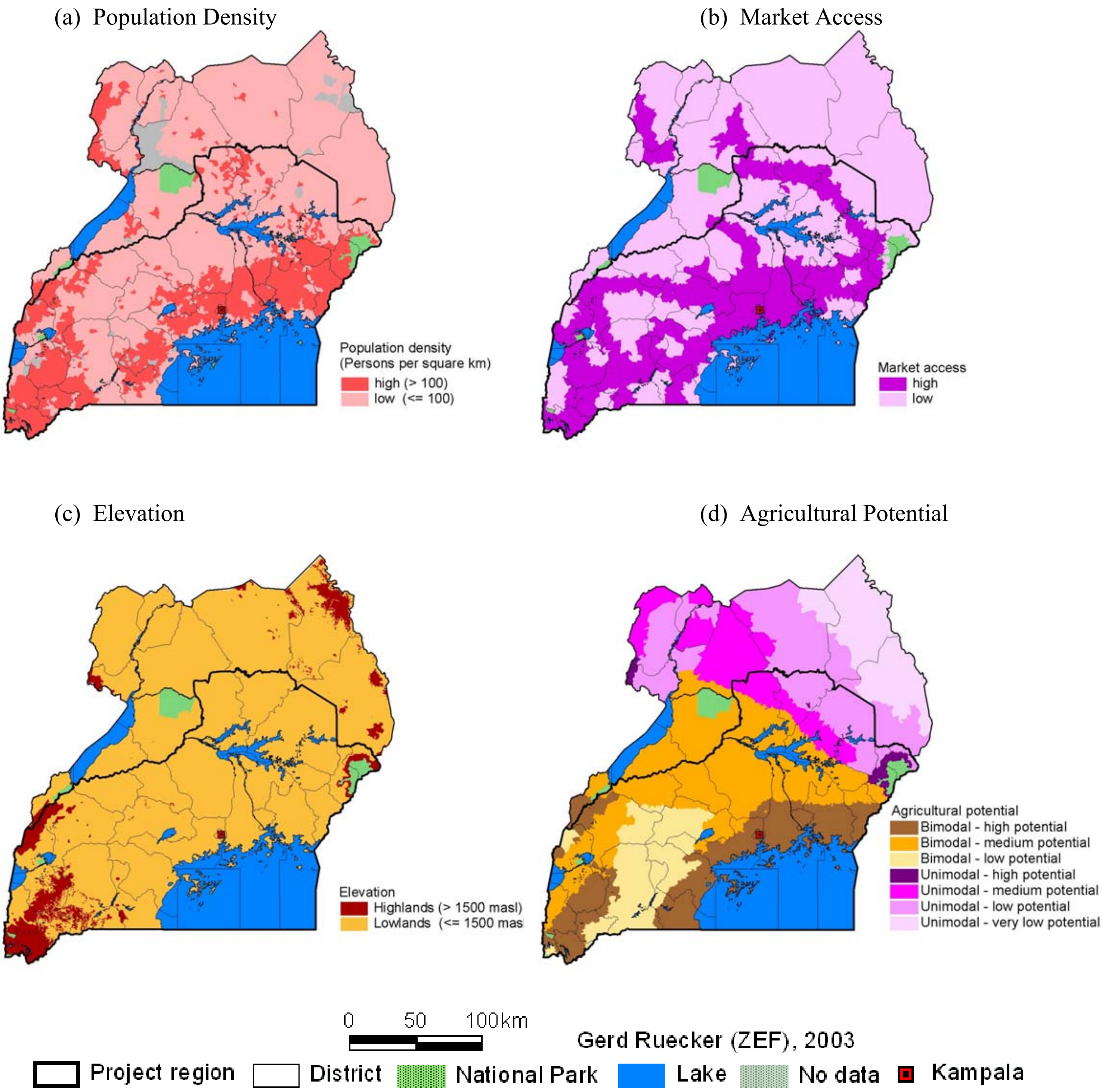
The input data to generate the spatial domain population density was defined as people per square kilometer. Population census at national level is performed in Uganda every ten years. The most recent data available are the 1991 National Population and Housing Census Summaries that were published in 1992 by the Ministry of Finance and Economic Planning (United Nations, 1994). The national census data contains 39 Districts, 163 Counties, 809 Sub-counties, 4234 Parishes and 72852 Enumeration areas (Guillaume and Lambotte, 1998). The highest spatial resolution of digitally available administrative data for the whole of Uganda is data in GIS-vector format at the administrative level of parishes (Ministry of Natural Resources, Department of Forestry, Uganda, 1999). Population density in parishes was classified as low, if there were equal or less than 100 people/km^2 and it was classified as high, if the ratio was greater than 100 people/km^2. Based on similar stratification studies in Ethiopia and Kenya (Braun et al., 1997), average rural and urban population density was found to be a suitable cut-off indicator for classifying population density also for Uganda, which yielded in that case about 100 people/km^2 on average. The high population density areas comprise 20.78% of Uganda's total area and are concentrated in favourable agricultural areas of Lake Victoria Crescent and Highlands. On the contrary, the low population density areas take an almost three times larger land share (67.01%). They cover the whole semi-arid territory from the northern region to the south-western part of the cattle corridor. For the remaining area there was no population (9.14%) as in national parks or water bodies and for 3.07% of Uganda's area data were missing (Figure 2 (a)).

4.2.2 Market Access

In this research, market access has been defined as potential market integration (PMI) (Deichmann, 1997). For any location the PMI represents an accumulated index of the travel time to the nearest market locations, weighted by the population of each market location. "Nearest" is assessed in terms of lowest travel time across a transport network (including off-road travel time to reach the closest network point), and for our stratification procedure, the nearest three target locations were used to build the index (Chou, 1997). Market locations were defined as settlements with more than 1,500 inhabitants. Travel times along any segment of the transport network depend upon travel speed, which in turn is reflected by the nature of the road surface. The variables that determine market access are Euclidean distance from the community to the nearest urban centers, which was based on data from the World Resource Institute (1999) and classified by Wood, et al. (1999). They divide the market access in high versus low. The road and community information is based on digital information derived from topographic maps of Uganda at a scale of 1: 50.000 (Directorate of Overseas Surveys for Uganda Government, 1963-1964). PMI was finally processed in raster format at a resolution of 5 x 5 km. The market access spatial distribution mirrored distribution of population density with 70% of the total area of

Uganda characterized by low market access and 21% of the total area by high market access (Figure 2 (b)).

Figure 2: Input Domains for Spatial Stratification of Uganda

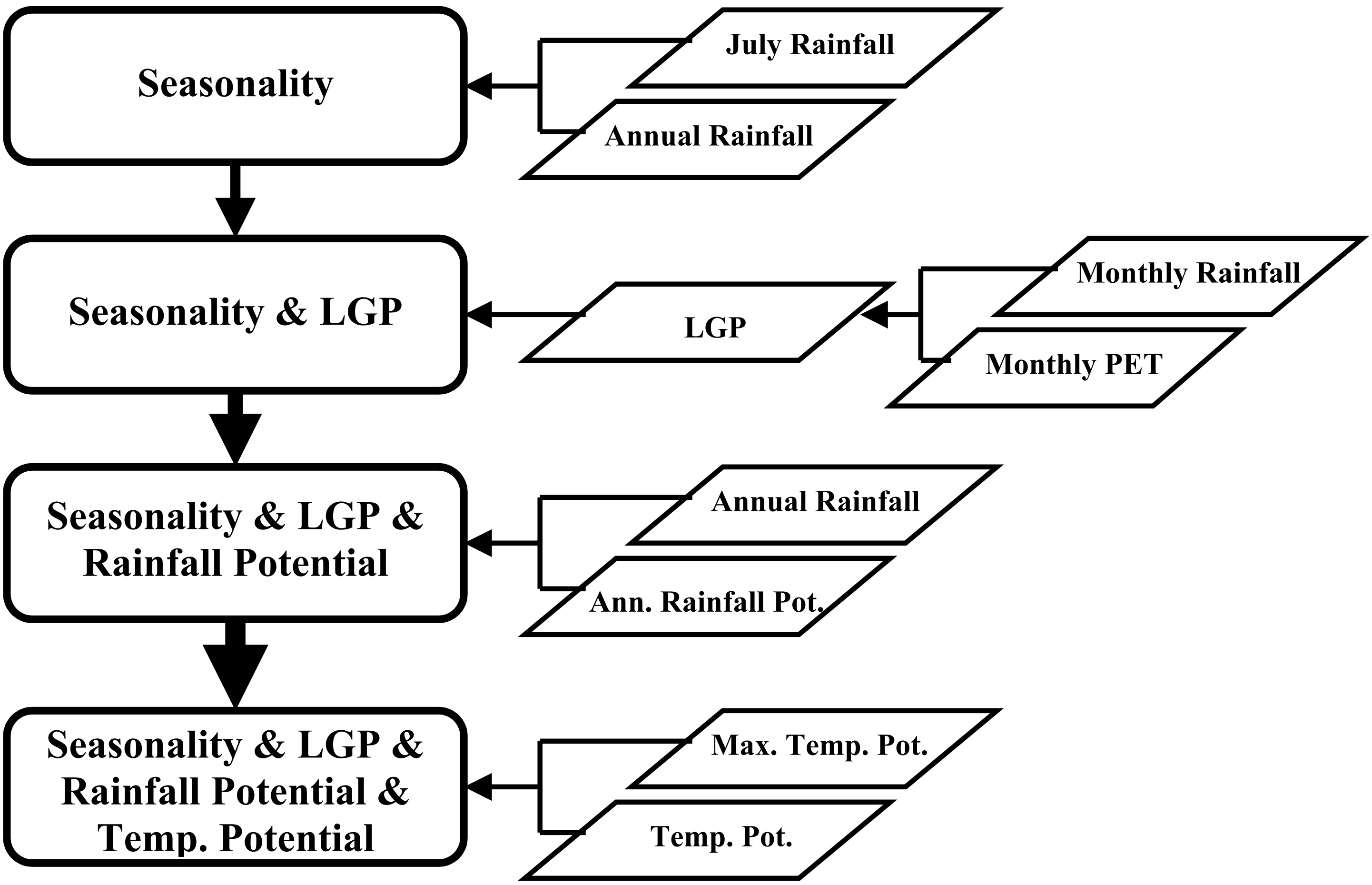


4.2.3 Agricultural Potential

Agricultural potential relies on many different natural conditions, including soil quality, climatic patterns and pest occurrence. Several strategies to evaluate the agricultural potential of land have been generated in the past. They focus on soil capability, climatic possibility and limitations or suitability of the physical resources to match requirements of crops (Klingebiel and Montgomery, 1966; Papadakis, 1970; FAO, 1996; Sys, *et al.,* 1993). The diversity of crops is very high in the humid tropics of Uganda (De Langhe, *et al.*, 1996). For example, more than sixty different crops, vegetables and fruit trees were identified in a detailed plot level assessment in two sites representing the banana-coffee and the highland farming systems in Uganda (Ruecker, 2003). Since the specific physical plant requirements were not yet known for many of those indigenous plants, the previous approaches were not directly applicable to capture the great diversity of agricultural plants in the wide study area.

A new hierarchical classification scheme was therefore developed to classify the agricultural potential of Uganda (Figure 3).

Figure 3: Hierarchical Classification Scheme of Agricultural Potential



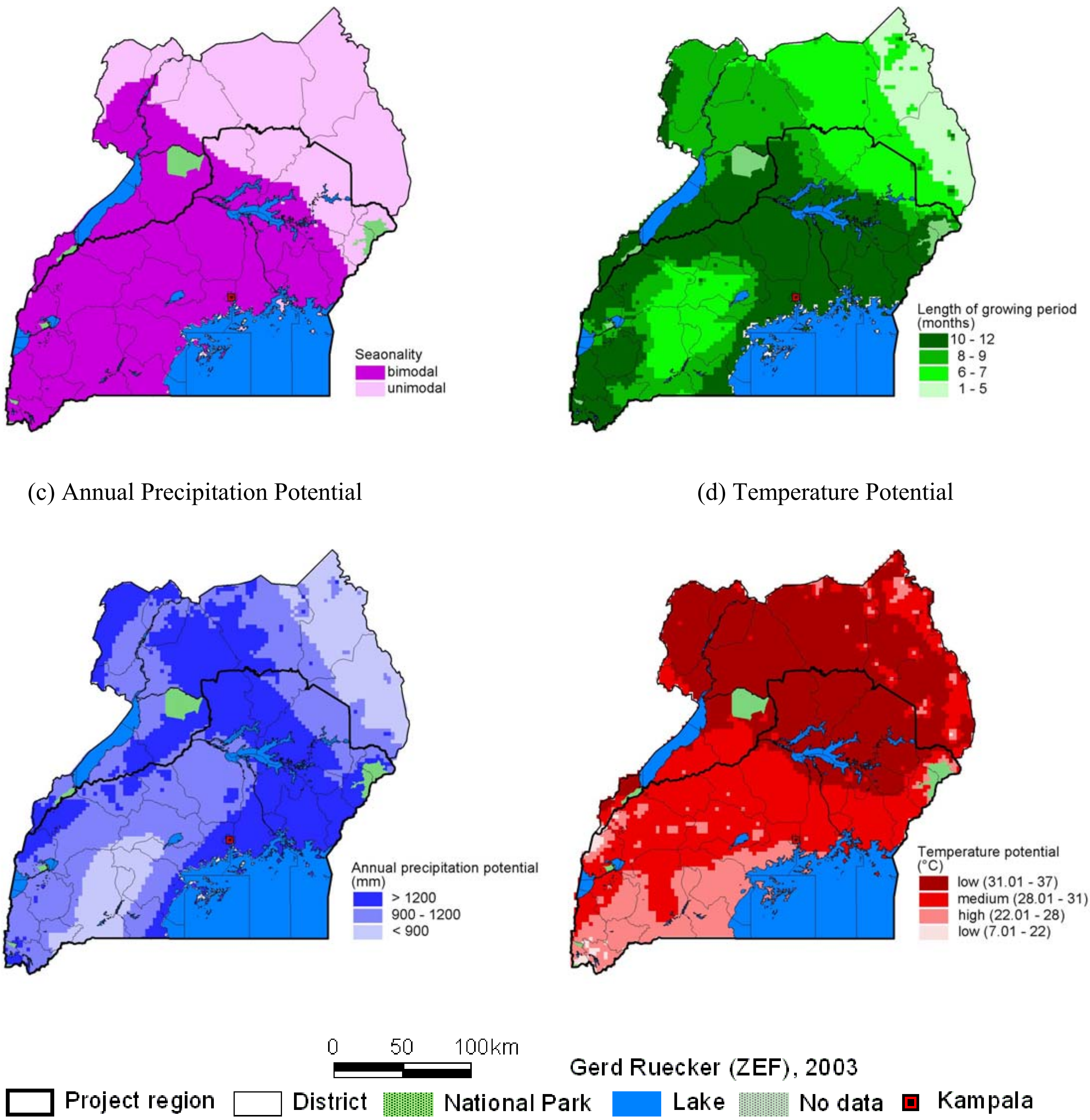
Due to the lack of soil information at the necessary detail and their unknown interaction with different crop species, the stratification procedure was mainly based on agro-climatic factors. The specific crop growth strongly depends on climatic conditions, and there are large differences in suitability of climate for individual crops. Banana (Musa spp., ´matooke´, East African highland cooking bananas) was selected as the reference crop for the proposed agro-climatic factors. Matooke is the dominant crop in Uganda, which is grown by 72% of the farmers and covers approximately 1.4 million hectares with a total production of 8.4 million tons per annum (Karugaba and Kimaru, 1999). Physical resource requirements for banana production were used according to Sys *et al.* (1993), Karugaba and Kimaru (1999) and adapted to the requirements of the local matooke species (Ssali, 2000).

This model uses seasonal rainfall pattern, length of growing period as well as annual rainfall potential and annual temperature potential to classify agricultural potential (Ssali, 2000). The climatic variables, which were identified to determine the suitability of land to produce Matooke, were: rainfall in July [mm], annual rainfall [mm], monthly rainfall [mm], maximum temperature in February [°C] and monthly potential evapotranspiration [mm]. All climatic data were from the digital data base ´Spatial Characterization Tool – Africa´ at a spatial resolution of 5.05° x 5.05° (Corbett and O´Brian, 1999, Corbett, 1995). Climatic coefficients for the tool were generated from Hutchinson *et al.* (1995). The proportion of mean July rainfall, which is the time period with lowest rainfall in bimodal rainfall areas, to mean annual rainfall can be used in Uganda to indicate rainfall modality (Wortmann and Eledu, 1999). A high proportion of rainfall in July characterizes a unimodal rainfall distribution, whereas a low proportion indicates a bimodal season (Figure 4 (a)). The length of growing period was defined as the period in which mean monthly rainfall exceeds half the mean potential evapotranspiration (FAO, 1996) (Figure 4 (b)). Annual rainfall potential was classified in low, medium and high categories, with less than 900 mm, between 900 mm and 1200 mm and more than 1200 mm mean annual rainfall, respectively (Figure 4 (c)). Mean maximum temperature in February was used to assess temperature potential in relation to its impact on crop growth. Relatively low temperatures of the upper highland zones and extreme high temperatures that occur mainly in the north of Uganda limit crop growth of perennial crops. Cut-off levels were set to low temperature potential because of relatively cold or hot temperature and to high or medium temperature potential because of optimum or sub-optimum temperature in February (Sys et al., 1993). Those temperature potentials were adjusted to local conditions to 7.1 – 22 °C, 31.01 – 37 °C, 22.01 – 28 °C, 28.01 – 31 °C, respectively (Figure 4 (d)).

Figure 4: Dominant Spatial Domains that Determine Agricultural Potential in Uganda

(a) Seasonality

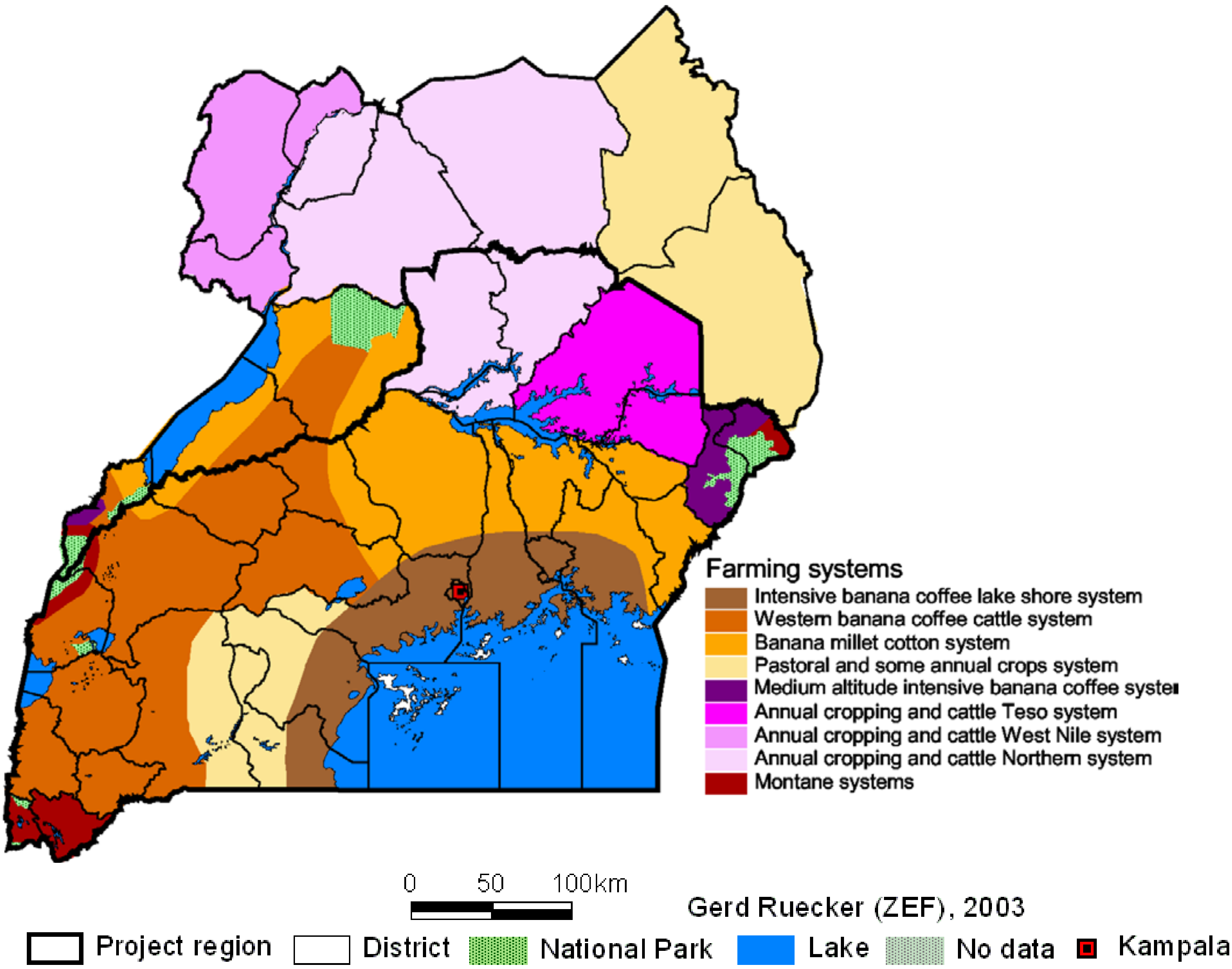
(b) Length of Growing Period



Based on that hierarchical classification model seven different agricultural potential zones were distinguished for the whole territory of Uganda (Figure 2 (d)). Three of those zones comprise bimodal agricultural areas. They are located in the south and in the central region. Agricultural potential of those zones range from high over medium to low with area extents comprising 25%, 28% and 9% of Uganda’s total territory, respectively. The remaining four zones are unimodal agricultural potential areas and cover high, medium, low and very low potential regions in the north of Uganda. The relative area extent of those zones is 1%, 10%, 18% and 9% respectively. Since six months of rainfall, if a continuous growing season provides high potential for annual crops, the low, medium and high agricultural potential in the unimodal rainfall area were combined together for the following analyses.

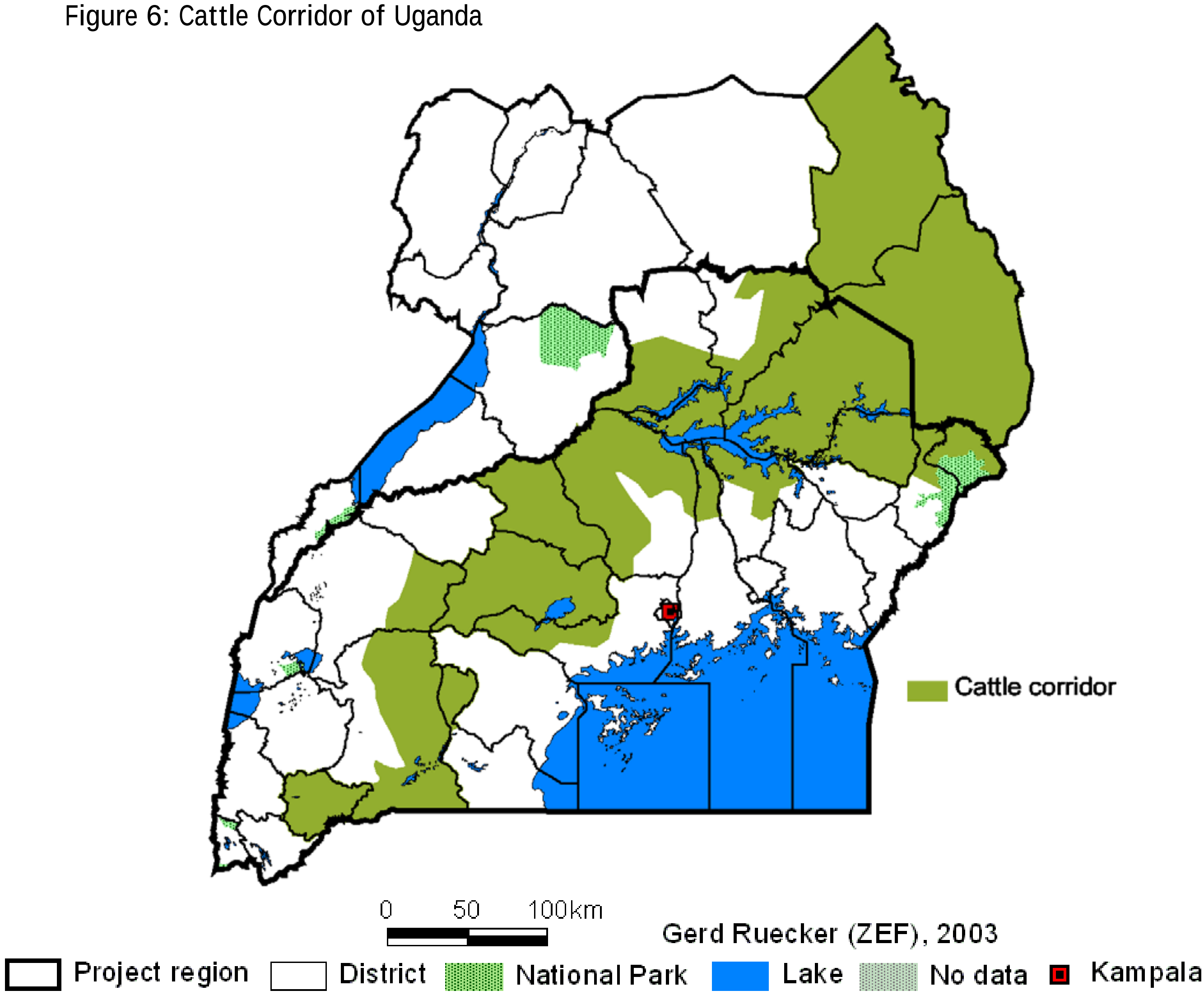
Parsons (1970) and Bashaasha (2001) divide the whole territory of Uganda into nine major farming systems (Figure 5): Intensive banana-coffee lakeshore system, 2) medium altitude intensive banana-coffee system, 3) western banana-coffee-cattle system, 4) banana-millet cotton system, 5) annual cropping and cattle Teso system, 6) annual cropping and cattle West Nile system, 7) annual cropping and cattle Northern system, 8) pastoral and some annual crops system, and 9) montane systems.

Figure 5: Major Farming Systems of Uganda



A comparison between Figure 2 (d) and Figure 5 shows a close resemblance between Uganda's main farming systems and the stratified agricultural potential developed for this research. As an example, annual cropping and pastoral systems are dominant in the area with unimodal agricultural potential, whereas perennial cropping systems are prevailing in the area governed by bimodal agricultural potential. There is even a strong correlation between individual farming systems and agricultural potential zone in the bimodal area. The Lake Victoria Crescent, which is characterized as the intensive banana coffee lakeshore system, reasonably matches with the bimodal agricultural potential zone, except at the south-western highland zone that corresponds with the montane farming system. Similar spatial coincidence occurs also between the bimodal low potential zone and the pastoral and some annual crops system in southern Uganda. This area is known as the southern part of the cattle corridor, that shows low agricultural potential (rainfall is less than 1000 mm and is erratically distributed over two seasons) between bimodal high agricultural potential zones (Figure 6). The western banana-coffee-cattle system and banana-millet cotton system belong to the bimodal medium agricultural potential zone. The close spatial resemblance with existing farming systems indicates that the proposed algorithm successfully separates the spatial distribution of agro-ecological potentials over the whole of Uganda.

Figure 6: Cattle Corridor of Uganda



4.2.4 Elevation

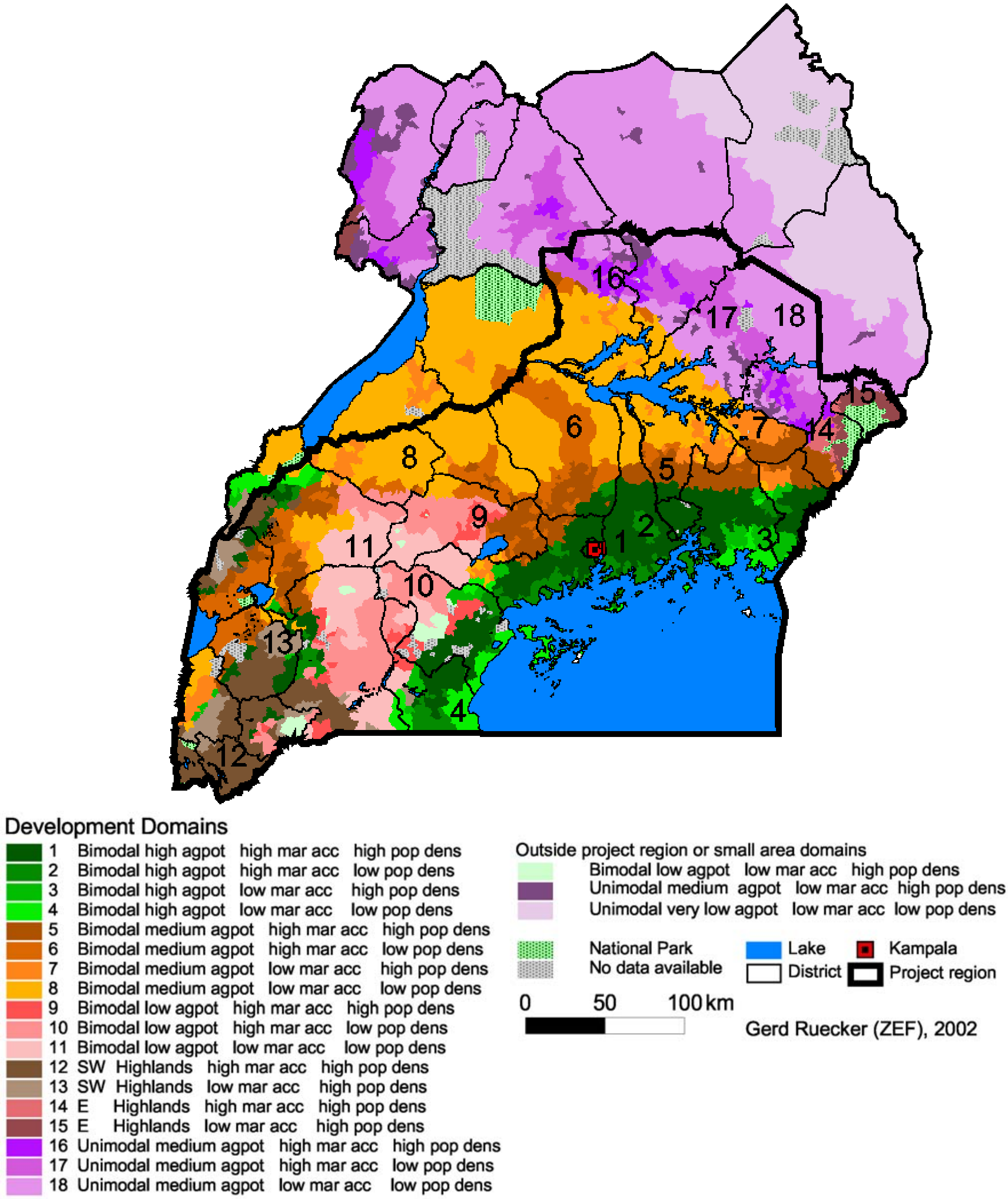
In Uganda where landscape is generally gentle and undulating, volcanic origin highland areas show unique agro-ecological and consequently significant development potentials (Ssali, 2001). Various indicators and cut-off levels were used in previous research in East-Africa to differentiate highlands from lowlands. In an ICRAF study to assess the potential for agroforestry in the highlands, Djimde and Hoekstra (1988) defined the criteria for highlands as areas with annual rainfall above 1000 mm and elevation ranging from 1000 to 2500 masl. The African Highlands Initiative (AHI) demarcates highlands as areas with more than 400 mm rainfall in five consecutive months and elevation range between 1200 and 3300 masl (Hoekstra and Corbett, 1995). Following similar cut-off criteria as in previous studies in Uganda, highlands were defined here as areas above 1500 masl, whereas mid ranges cover areas between 1000 masl and 1500 masl and lowlands are below 1000 masl. This classification was applied to digital elevation data at a resolution of 1 x 1 km (Hutchinson, 1995).

The highlands are demarcated in the eastern and western rift valley. In the eastern rift valley the highlands are concentrated in the areas of the great volcanoes such as the Mount Elgon (4321 masl) and Mount Kadam (3068 masl). The western highlands are known as the Rwenzoris, the Mountains of the Moon (5113 masl), whereas the highlands in the southwest range up to volcanoes such as the Mount Muhavura (4140 masl). The West Nile uplands along the border with the Republic of Congo in the northwest are part of the eastern flank of the western rift valley and reach up to 1500 masl. Surrounded by these highland areas is a raised plateau, which covers the majority of the area in the center of Uganda and ranges between 1000 and 1500 masl. The area in the northeast buffering the Albert Nile has less than 1000 masl and is classified as lowland. For reasons of simplifications and to clearly demarcate the highlands from the rest of the area, lowland and mid ranges were combined in one lowland class. The highlands cover 5.5% of Uganda’s area, while the lowlands have a share of 94.5%.

4.2.5 Development Domains and their Spatial Extent

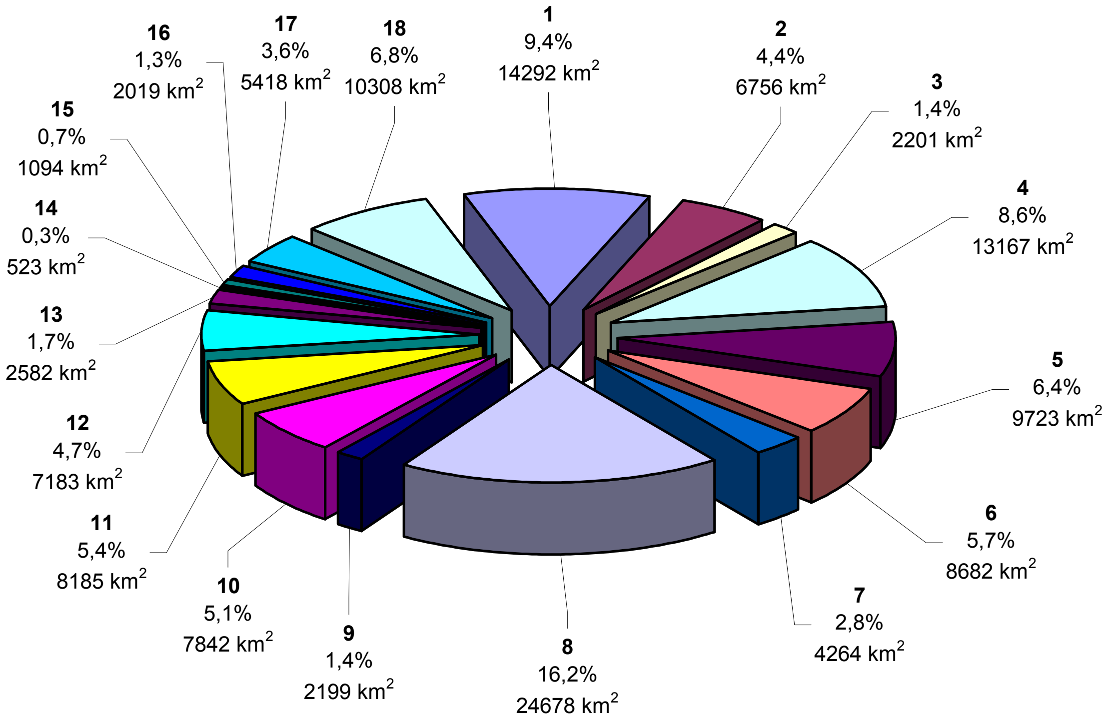
After spatial domains of population density, market access, agricultural potential and highland areas were independently modeled in the GIS, final stratification was performed by a spatial overlay of all four input domains in which each spatial domain was equally weighted. Considering seven agricultural potential domains (including the highlands as separate agricultural potential domains and combining unimodal low and medium potential zones), and two domains of both population density and market access, twenty-eight strata were theoretically possible. However, some combinations of input domains were not existent in Uganda. These were the strata representing high population density, high market access, very low unimodal agricultural potential as well as low population density, high market access and very low unimodal agricultural potential. Combining the unimodal agricultural potential strata and adding four highlands strata separately resulted in twenty strata. Two strata were not further considered in the following selection of communities, because they represented less than 2% of the population and less than 2% of the area of the research region. Those strata were lowland, high population density, low market access, unimodal medium agricultural potential and lowland, high population density, low market access, bimodal low agricultural potential. One stratum in the northeast of Uganda was outside of the project region and was therefore not further considered. The final stratification represents eighteen development domains, which are presented in Figure 7.

Figure 7: Development Domains of Uganda



The development domains that are demarcated on the stratification map (Figure 7) are characterized by specific values of population density, market access, agricultural potential and elevation. Figure 8 shows the area extent of each development domain in absolute dimension and relative to the project region[2].

Figure 8: Development Domain Area Sizes



The sizes of those development domains vary considerably across Uganda. Development domains were clustered by simple classification of domains in groups of small, medium and large extent. The respective spatial location relationships were investigated for each domain of a cluster. The smallest development domains were classified by area extent less than 2 % of the project region. This resulted in units # 3, 9, 13, 14, 15 and 16. Domain # 3 for example is located along the Lake Victoria fringe adjacent to the Kenya border. In this corner position, market access is poor, while good market connection is provided in direct neighborhood (domain # 1) just some few kilometers further towards Kampala. Another example is domain # 9, which lies in the West/SW of Uganda at the rim of the relatively dry cattle corridor. Agricultural potential is low in that area, whereas agricultural potential is higher in the adjacent domains # 5 and 6. A third example is domain # 13. It can be found in a border zone in the southwest highlands. It lacks market access, whereas all other places surrounding it are well connected. Similar marginal positions and location-specific disadvantages occur for domains # 14, 15, and 16 (compare Figure 7).

[2] The small areas that were excluded earlier comprise 1.3%, and the Lake Victoria and National Parks cover 12.6% of the project region

In contrast, the largest development domains where classified by area sizes covering more than 8% of the project region. Those areas comprise domains # 1, 4 and 8. They are distributed as a belt around Lake Victoria. Domain # 1 is located within the central part of the Lake Victoria Crescent where agricultural conditions are favorable and Kampala and other big cities provide good market access leading to high population density. Southward adjacent is the location of domain # 4, which borders Lake Victoria. Although that area is just some few tens of kilometers apart from domain # 1, good market access is lacking already, because no major roads and cities are positioned there. The same market disadvantage applies for domain # 8, which is located north of domain # 1. The location of all other remaining development domains are in between those large belt and small border domains leading to mixed factor combinations of agricultural potential, population density and market access that again influences corresponding advantages and disadvantages.

5 Targeting Development Policies within Uganda

The GIS-based stratification of Uganda generated 18 development domains (Figure 7). Although development domains were classified as homogenous areas, the variability of those indicators that were used in the stratification within a domain might vary considerably (e.g. annual rainfall potential, length of growing period). Minimum and maximum ranges of those natural resource and socio-economic indicator values[3] are presented together with more statistical information in Table 2. Those detailed indicator values may be useful as inputs for regional agricultural policy analysis where quantitative and spatially disaggregated information is desired, e.g. to assess land suitability for crop cultivation, to support decisions on site-specific fertilizer strategies or to model human's socio-economic behavior.

Based on site-specific requirements of major land use and livelihood strategies, the conditions of development domains are evaluated in terms of their comparative advantages and disadvantages to meet those strategies. Potential development pathways are then hypothesized to strengthen advantages and to relax disadvantages of those domains for optimization of land use and livelihood types. Policy makers may use that spatial information as a guide in prioritizing and targeting policies, institutional and land management investments to certain development domains.

[3] Variables for classification of market access were not further specified since these data were only available from an aggregated index (Wood, et al., 1999).

Table 2: Specific Indicator Values of Development Domains
(Mean Values that are Particularly High for a Given Indicator are bold, while Particular Low Values or Underlined)

Domain #	July rainfall [mm]				Annual rainfall potential [mm]				Growing period [months]				Temperature potential [°C]				Population density [persons / km²]				Elevation [m]			
	n	mean	min	max	n	mean	min	max	n	mean	min	max	n	mean	min	max	n	mean	min	max	n	mean	min	max
1	2229	58	14	124	710	1198	837	1464	45	9,7	7	12	469	28,6	23,4	30,8	819	**1223**	101	26577	14953	1224	1028	2496
2	452	49	13	83	356	1240	787	1463	29	**9,9**	7	12	216	28,0	24,3	30,8	86	99	3	3507	4551	1234	800	2169
3	271	56	12	92	167	1157	882	1347	14	9,1	7	11	73	28,8	25,9	30,8	74	187	103	419	2809	1211	915	1933
4	505	47	6	84	301	**1321**	833	1624	26	**10,0**	7	12	432	27,5	26,0	31,4	51	33	1	99	3641	1219	727	1556
5	1520	72	30	157	543	1178	916	1575	31	9,5	7	11	306	29,6	26,3	32,6	408	242	101	10877	11415	1176	864	2115
6	674	60	27	119	532	1132	916	1370	23	9,2	7	11	283	29,7	26,9	32,3	123	63	6	100	10538	1119	739	1795
7	623	79	29	145	306	1175	874	1586	15	9,1	7	10	142	30,4	25,5	32,8	155	195	101	2463	5594	1134	755	1810
8	2002	79	28	117	1007	1169	858	1353	22	9,1	7	11	799	30,7	23,2	32,8	287	49	1	99	25050	1097	610	2169
9	268	26	5	60	170	904	754	1100	13	8,0	6	9	74	27,7	25,8	28,9	70	229	101	1612	2750	1335	1151	1859
10	565	30	7	61	387	898	701	1239	18	8,2	6	10	250	28,3	24,8	29,9	89	49	7	99	9610	1300	1086	1781
11	475	28	4	48	384	882	706	1129	9	7,4	6	8	269	28,2	26,1	29,5	75	45	14	98	9648	1285	947	1749
12	1259	28	4	105	359	1099	755	1815	34	9,9	7	12	234	25,2	16,0	30,8	417	338	0	5741	8697	1694	1070	3944
13	340	36	5	127	163	1118	718	2083	22	9,5	7	12	83	24,7	7,1	29,2	81	198	27	1947	3458	**1873**	1059	4563
14	167	**133**	108	163	43	**1312**	1132	1575	1	9,0	9	9	15	29,2	23,6	30,6	52	**949**	42	7451	767	1383	1108	1992
15	237	**148**	120	164	79	**1278**	966	1586	7	7,7	7	9	35	27,8	23,8	31,3	83	423	6	1906	1470	**1713**	1169	2595
16	299	**124**	110	146	157	1256	1093	1416	7	8,1	7	9	66	**31,8**	28,6	32,8	83	535	102	5899	2820	1103	1002	1741
17	513	**124**	111	143	308	1232	1063	1408	8	8,1	7	9	177	**32,3**	30,8	33,2	111	66	4	122	6717	1080	998	1229
18	928	**124**	104	155	490	1165	886	1373	14	7,5	6	9	349	**32,4**	27,0	34,2	172	51	3	100	11595	1072	971	1768

5.1 Site-Specific Requirements of Major Land Uses and Livelihood Strategies

The main subsistence perennial food crop produced in Uganda is matooke, while several annual food crops are also produced for subsistence purposes, including sorghum, millet, cassava, and sweet potatoes as examples. Profitable production of matooke requires a site that has a relatively high annual amount of rainfall that is fairly equally distributed throughout the season, neither extreme high nor extreme low temperatures, high soil fertility, good drainage conditions and moderate rooting depth (Sys, et al, 1993). Crop and land management requires maintaining natural resource conditions or in case the conditions are not optimal, supplementing specific inputs (e.g. organic and inorganic fertilizers, water-harvesting structures). Matooke and those other above mentioned products are cultivated for cash purposes as well, in which case the marketability of these products becomes relevant. Matooke is perishable and costly to transport relative to its value, because of its high water content. Cash crop production of matooke is therefore expected to be more suited to areas of relatively high market access where agricultural potential is suitable and sufficient as well as skilled laborers are available to perform necessary crop and land management.

At first sight it might seem paradoxical that matooke production has been shifting from areas with high agricultural potential and close to the urban market Kampala to south-west Uganda where agricultural potential and market access is medium to low. This shift is reported due to pest problems (especially banana weevils and nematodes) and soil fertility problems in the Lake Victoria crescent (Gold, et al., 1999). On the other side it is reported that crop and land management (e.g. water harvesting) of farmers in the south-western highlands is more intensive than in the traditional production area of the Lake Victoria Region (Zake, et al., 1997; Gold, et al., 1999). These issues illustrate that sub-optimal natural resource conditions can be balanced by site-specific land management that is necessary to generate high quantity and quality products. If that production is connected to a good road infrastructure the value of these products can thus even outweigh the comparative disadvantage of longer distances to markets.

Fruits and vegetables are highly perishable and must either be processed or sold close to the field or produced close to markets. The requirements of Uganda’s great diversity of fruits and vegetables to climate and soil conditions vary largely, but most of them need high soil fertility, good water supply and intensive crop husbandry. Many annual food crops, such as cereals and pulses can tolerate extensive dry spells and can grow on many soil types. These crops can be dried and stored for extended periods and have a higher value per unit volume than matooke. These crops can therefore be produced further from markets in areas with medium to low agricultural potential. High value storable crops such as coffee and cotton may be profitable even far from markets, though they may also have a comparative advantage in areas of high market access. Site requirements of coffee (robusta species) are similar to that of matooke, as a result of which they are often cultivated together (compare map of farming systems Figure 5), whereas the growing requirements for cotton largely resemble those of cereal crops.

Similar considerations as for crops apply to production of livestock and livestock products. Intensive production of perishable products such as dairy is appropriate mainly in areas of high market access and high population density. Extensive production of high value livestock that are relatively easy to transport, such as cattle and small ruminants, can profitably be implemented in areas far from markets, and tends to have a comparative advantage in areas that are low in agricultural potential for crop production. Dairy products may also be produced in such extensive systems in lower potential areas, but high access to collection and processing facilities or to urban markets is essential. In areas where subsistence food production continues to be important (especially areas with low market access and of relatively high population density), mixed-crop livestock production often occurs, with farmers keeping small numbers of animals for ploughing, consumption and saving. This is because the benefits of exploiting complementarities between crop and livestock production rise as population density rises, particularly where markets are not well developed (McIntire et al., 1992).

Forestry production is likely to be suited to areas of low population density, since land scarcity in high-density areas usually causes intensive food or cash crop production to have higher value and priority. Production of high value forest products such as timber may be profitable in remote locations (provided that suitable road and transport infrastructure exists) with good rainfall supply and deep potential rooting space, while low value products such as fuel wood for sale must be produced close to markets, though are possible in poorer water and soil conditions.

Rural non-farm employment activities are linked to agriculture in most of the cases. This includes industries processing agricultural commodities (e.g. coffee processing, cotton milling, sugarcane processing), commodity traders, and individuals and firms providing agricultural inputs. These activities are also more significant in areas of higher population density close to urban centers. Since these activities do not directly require natural resources, agricultural potential is not relevant for their actual site, although a close spatial association to sites with good agricultural potential where the products are cultivated is beneficial to reduce costs of transport. Potentials for rural people to be employed in rural non-farm activities that are not linked to agriculture, such as mining, construction, and in urban areas are presently very limited (NEMA, 1999).

5.2 Targeting Development Pathways to Development Domains

Based on the different factors determining agricultural development in Uganda and the major environmental as well as socio-economic conditions, comparative advantages and disadvantages for different agricultural activities are summarized for each development domain in Table 3.

Table 3: Advantages, Disadvantages and Pathways of Development in Development Domains

Domain #	Districts mostly covered	Major environmental and socio-economic conditions	Comparative advantages	Comparative disadvantages	Potential pathways of development
1	IGANGA KAMPALA MASAKA MPIGI MUKONO RAKAI	- Bimodal high agricultural potential - High market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. perishable fruits, vegetables) and inputs - High population density, existence of large cities to encourage rural industry and urban employment - Intensive farming due to good access to credit, technology and extension service - Favorable agro-climatic and market conditions for dairy and other livestock production	- High soil degradation due to intensive farming - Strong soil erosivity due to heavy rainfalls - High pest and diseases pressure on crops - High land fragmentation due to high population pressure - Land shortage for small scale farmers due to increasing land cultivation by large-scale estates (e.g. sugarcane, flower production)	- Intensify perennial cash crops - Intensify perishable annual cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture - Promote urban employment - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies
2	MPIGI MUKONO RAKAI	- Bimodal high agricultural potential - High market access - Low population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. perishable fruits, vegetables) and inputs - Intensive farming due to good access to credit, technology and extension service - Favorable agro-climatic and market conditions for dairy and other livestock production - Favorable conditions for fishing and fish farming - Favorable agro-climatic and population conditions of forest production	- Strong soil erosivity due to heavy rainfalls - High pest and diseases pressure on crops - Land shortage for small scale farmers due to increasing land cultivation by large-scale estates (e.g. sugarcane, flower production)	- Intensify perennial cash crops - Intensify perishable annual cash crops - Increase intensive dairy production - Intensify other livestock production - Intensify fishing and fish farming - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies - Produce high value forest products
3	BUGIRI BUSIA IGANGA MASAKA RAKAI	- Bimodal high agricultural potential - Low market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and annual crops (e.g. pulses, root crops) - High population density and existence of cities to encourage rural industry and urban employment - Favorable agro-climatic and market conditions for dairy and other livestock production - Favorable conditions for fishing and fish farming	- High soil degradation due to intensive farming - Strong soil erosivity due to heavy rainfalls - High pest and diseases pressure on crops - High land fragmentation due to high population pressure - Land shortage for small scale farmers due to increasing land cultivation by large-scale estates (e.g. sugarcane, flower production) - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology, extension	- Intensify perennial cash crops - Intensify perishable annual cash crops - Intensify other livestock production - Promote urban employment - Intensify fishing and fish farming - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies - Increase access to credit and technology

Domain #	Districts mostly covered	Major environmental and socio-economic conditions	Comparative advantages	Comparative disadvantages	Potential pathways of development
4	KALANGALA MASAKA MUKONO RAKAI	- Bimodal high agricultural potential - Low market access - Low population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and annual crops (e.g. pulses, root crops) - Favorable agro-climatic and market conditions for dairy and other livestock production - Favorable conditions for fishing and fish farming - Favorable agro-climatic and population conditions of forest production	- Strong soil erosivity due to heavy rainfalls - High pest and diseases pressure on crops - Land shortage for small scale farmers due to increasing land cultivation by large-scale estates (e.g. sugarcane, flower production) - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology and extension service	- Intensify perennial cash crops - Intensify perishable annual cash crops - Intensify other livestock production - Produce high value forest products - Intensify fishing and fish farming - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies - Increase access to credit and technology
5	IGANGA KABAROLE LUWEERO	- Bimodal medium agricultural potential - High market access - High population density	- Moderate agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and favorable conditions for annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. perishable fruits, vegetables) and inputs - High population density and existence of cities to encourage rural industry and urban employment - Intensive farming due to good access to credit, technology and extension service	- High soil degradation due to intensive farming - High pest and diseases pressure on crops - High land fragmentation due to high population pressure - Land shortage for small scale farmers due to increasing land cultivation by large-scale estates (e.g. sugarcane, flower production)	- Intensify perennial cash crops - Intensify annual cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture
6	KABAROLE KASESE KIBOGA LUWEERO NAKASON-GOLA	- Bimodal medium agricultural potential - High market access - Low population density	- Moderate agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and favorable conditions for annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. perishable fruits, vegetables) and inputs - Intensive farming due to good access to credit, technology and extension service - Favorable agro-climatic and population conditions of forest production	- High pest and diseases pressure on crops	- Expand perennial cash crops - Expand annual cash crops - Produce high value forest products
7	KAMULI KIBAALE PALLISA RUKUNGIRI	- Bimodal medium agricultural potential - Low market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. cotton, millet) and favorable conditions for annual crops (e.g. pulses, root crops) - High population density and existence of cities to encourage rural industry and urban employment - Favorable agro-climatic and market conditions for livestock production	- High soil degradation due to intensive farming - High land fragmentation due to high population pressure - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology and extension service	- Intensify subsistence perennial crops - Intensify subsistence mixed livestock - Intensify storable perennial cash crops - Intensify storable annual cash crops - Increase access to credit and technology - Produce high value forest products

Domain #	Districts mostly covered	Major environmental and socio-economic conditions	Comparative advantages	Comparative disadvantages	Potential pathways of development
8	APAC KIBALE KIBOGA LUWEERO	- Bimodal medium agricultural potential - Low market access - Low population density	- Moderate agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) and favorable conditions for annual crops (e.g. pulses, root crops) - Favorable agro-climatic and market conditions for dairy and other livestock production - Favorable agro-climatic and population conditions of forest production	- Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology and extension service	- Expand subsistence perennial food crops - Expand subsistence annual food crops - Expand storable perennial cash crops - Expand storable annual cash crops - Increase extensive livestock production - Produce high value forest products - Increase access to credit and technology
9	MASAKA MBARARA MUBENDE RAKAI	- Bimodal low agricultural potential - High market access - High population density	- Moderate agro-climatic conditions for cultivation of annual crops (e.g. cereals, pulses) - High market access for annual cash crops and inputs - Favorable agro-climatic and market conditions for dairy and other livestock production - High population density and existence of cities to encourage rural industry and urban employment	- Marginal agro-climatic conditions for cultivation of perennial crops (e.g. coffee, Matooke) - high soil degradation due to intensive farming - high land fragmentation due to high population pressure	- Expand annual subsistence and cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture
10	KABAROLE MASAKA MBARARA MUBENDE	- Bimodal low agricultural potential - High market access - Low population density	- Moderate agro-climatic conditions for cultivation of annual crops (e.g. cereals, pulses) - High market access for annual cash crops and inputs - Favorable agro-climatic and market conditions for dairy and other livestock production	- Marginal agro-climatic conditions for cultivation of perennial crop growth (e.g. coffee, Matooke)	- Expand annual subsistence and cash crops - Increase livestock production - Increase intensive dairy production - Rural industry linked to agriculture
11	KABAROLE MBARARA MPIGI MUBENDE	- Bimodal low agricultural potential - Low market access - Low population density	- Moderate agro-climatic conditions for cultivation of annual crops (e.g. cereals, pulses) - Storage of annual crops (e.g. cereals, pulses) can balance poor market access - Favorable agro-climatic conditions for livestock production	- Marginal agro-climatic conditions for cultivation of perennial crop growth (e.g. coffee, Matooke) - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology and extension service	- Increase extensive livestock production - Increase drought resistant annual crop production - Increase access to credit and technology
12	BUSHENYI KABALE KISORO MBARARA NTUNGAMO	- SW Highlands - Bimodal high agricultural potential - High market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. cotton, millet) and favorable conditions for annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. irish potatoes, perishable fruits, vegetables) and inputs - High population density and existence of cities to encourage rural industry and urban employment - Favorable agro-climatic and market conditions for dairy and other livestock production - Intensive farming due to good access to credit, technology and extension service	- High soil degradation due to intensive farming - High land fragmentation due to high population pressure	- Intensify perennial cash crop production - Intensify annual cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies
13	BUSHENYI KASESE NTUNGAMO RUKUNGIRI	- SW Highlands - Bimodal high agricultural potential - Low market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. cotton, millet) and annual crops (e.g. pulses, root crops) - High population density and existence of cities to encourage rural industry and urban employment - Favorable agro-climatic and market conditions for dairy and other livestock production	- High soil degradation due to intensive farming - Strong soil erosivity due to heavy rainfalls - High land fragmentation due to high population pressure - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology, extension	- Intensify subsistence perennial crops - Intensify subsistence mixed annual livestock - Intensify storable perennial cash crops - Intensify storable annual cash crops - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies

Domain #	Districts mostly covered	Major environmental and socio-economic conditions	Comparative advantages	Comparative disadvantages	Potential pathways of development
14	KAPCHORWA MBALE	- E Highlands - Unimodal high agricultural potential - High market access - High population density	- Favorable agro-climatic conditions for perennial cropgrowth (e.g. coffee, Matooke) and annual crops (e.g. pulses, root crops) - High market access for cash crops (e.g. coffee, Matooke, perishable fruits, vegetables) and inputs - Favorable agro-climatic and market conditions for dairy and other livestock production - Favorable agro-climatic conditions for forest growth	- High soil degradation due to intensive farming - Strong soil erosivity due to heavy rainfalls - High land fragmentation due to high population pressure	- Intensify perennial cash crops - Intensify annual cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture - Produce high value forest products - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies
15	KAPCHORWA MBALE	- E Highlands - Unimodal high agricultural potential - Low market access - High population density	- Favorable agro-climatic conditions for cultivation of perennial crops (e.g. millet) and for annual crops (e.g. pulses, root crops) - Favorable agro-climatic conditions for forest growth - High population density and existence of cities to encourage rural industry (e.g. timber processing)	- High soil degradation due to intensive farming - Strong soil erosivity due to heavy rainfalls - High land fragmentation due to high population pressure - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology and extension service	- Intensify subsistence perennial crops - Intensify subsistence mixed annual livestock - Intensify storable perennial cash crops - Intensify storable annual cash crops - Produce high value forest products - Intensify agricultural extension service to teach farmers integrated nutrient management and soil/water conservation strategies - Increase access to credit and technology
16	APAC KUMI LIRA	- Unimodal medium agricultural potential - High market access - High population density	- Favorable conditions for annual crops (e.g. cereals, pulses) storable products such as cotton - Intensive farming due to good access to credit, technology and extension service - Favorable agro-climatic and market conditions for dairy and other livestock production - High population density and existence of cities to encourage rural industry and urban employment	- Marginal agro-climatic conditions for cultivation of perennial crop growth (e.g. coffee, Matooke)	- Intensify annual cash crops - Increase intensive dairy production - Intensify other livestock production - Rural industry linked to agriculture - Produce high value forest products
17	APAC KATAKWI KUMI LIRA SOROTI	- Unimodal medium agricultural potential - High market access - Low population density	- Favorable conditions for annual crops (e.g. cereals, pulses) storable products such as cotton - Favorable conditions for storable perennial crops such as cotton - High population density and existence of cities to encourage rural industry and urban employment - Favorable agro-climatic and market conditions for dairy and other livestock production	- Marginal agro-climatic conditions for cultivation of perennial crop growth (e.g. coffee, Matooke)	- Expand annual cash crops - Rural industry linked to agriculture - Increase intensive dairy production - Intensify other livestock production
18	KATAKWI LIRA	- Unimodal medium agricultural potential - Low market access - Low population density	- Favorable conditions for storable perennial crops such as cotton and annual crops (e.g. cereals, pulses) - Favorable agro-climatic conditions for livestock production	- Marginal agro-climatic conditions for cultivation of perennial crop growth (e.g. coffee, Matooke) - Poor access to markets to sell cash crops and to buy inputs - Poor access to credit, technology, extension service	- Expand subsistence annual food production - Expand storable annual cash crops - Increase extensive livestock production - Increase access to credit and technology

There are many types and combinations of livelihood strategies and land uses that have comparative advantages and disadvantages in a specific development domain. Therefore the list in the table cannot be exhaustive, but may help policy makers identify and assess dominant natural and socio-economic conditions for spatial domains. In order to support direct transfer of that development domain information to official decision making units in Uganda, reference of major development domains to each district is presented in Table 4[4].

Table 4: Major Development Domains within Districts of Research Region

District #	District Name	Domain #
1	APAC	8, 17, 18
2	BUGIRI	4
3	BUSHENYI	1, 6, 12 , 13
4	BUSIA	1, 3
5	IGANGA	1, 5
6	JINJA	1
7	KABALE	12
8	KABAROLE	5, 6, 8, 10, 11
9	KALANGALA	4
10	KAMPALA	1
11	KAMULI	1, 5, 7, 8
12	KAPCHORWA	15, 18
13	KASESE	1, 5, 6, 13
14	KATAKWI	17, 18
15	KIBAALE	7, 8
16	KIBOGA	6, 8
17	KISORO	12
18	KUMI	16, 17, 18
19	LIRA	8, 16, 17, 18
20	LUWEERO	5, 6,8

District #	District Name	Domain #
21	MASAKA	1,4,10
22	MBALE	5,14,15,18
23	MBARARA	10,11,12
24	MPIGI	1,2,11
25	MUBENDE	5,6,10,11
26	MUKONO	1,2,4
27	NAKASONGOLA	6,8
28	NTUNGAMO	10,12,13
29	PALLISA	5,7,8
30	RAKAI	1,2,4,11
31	RUKUNGIRI	7,8,12,13
32	SOROTI	8,17,18
33	TORORO	1,5,7

[4] Dominant development domains are classified as those domains that cover more than 10% of a district's area.

Sserunkuuma et al. (2001) hypothesized 20 possible development pathways in Uganda[5]. Six of these include intensification of crop or mixed crop-livestock production. Six of these involve expansion of crop production (annuals for subsistence, storable annuals for cash, perishable annuals for cash, perennials for subsistence, storable perennials for cash, and perishable perennials for cash). One is expansion of extensive livestock production (cattle or small ruminants) while two involve intensive livestock production (dairy and other livestock). Two involve increased production of forestry products (high or low value). Two involve rural industry (linked or not linked to agriculture), and the final pathway is increased employment in urban areas. Since some domains are expected to greatly benefit from an improved agricultural extension service, this pathway of development was found necessary to be added.

The intensive livelihood strategies are appropriate to high-density areas, while the extensive crop and livestock strategies are expected to have comparative advantage mainly in low population density areas. Perishable crop and livestock products should be produced close to markets, whereas storable crops may be produced in areas of either high or low access. Perennial crops are expected to be suited more to the bimodal rainfall regions whereas longer duration annuals (such as maize) are suited to all regions except the bimodal low rainfall region (though having higher potential in the areas classified as high than those classified as medium or low). Forestry activities are expected to have comparative advantage mainly in low population density areas of at least medium rainfall, with low value products requiring good market access (if production is for cash purposes) and high value products may be produced in areas of either high or low access. Rural industry (whether or not linked to agriculture) will be most common in more densely populated areas close to markets, while urban employment is likely common mainly close to Kampala.

[5]The hypothesized pathways of development are modified after Sserunkuuma et al. (2001) and complemented for development domains # 2, 3 and 4 that were not considered by those authors.

6 Conclusions

It is widely believed that many previous policy recommendations were too broad to accommodate the diverse natural and socio-economic conditions of a region. With respect to these limitations, we reviewed different methodologies to integrate those conditions for specific development objectives. That discussion resulted in a GIS-based stratification strategy to capture spatial resource complexity at national scale with application to Uganda.

According to pathways of development theory, we selected population density, market access, agricultural potential and elevation as the main input factors to separate the spatial domains of agricultural development in Uganda. This stratification resulted in 18 development domains covering more than two third of Uganda’s area. For all of these development domains we assessed opportunities and constraints concerning main land uses and agricultural livelihood strategies. This assessment guided us to propose strategic development pathways that are targeted to those development domains. Those domains were translated to actual administrative units of Uganda to make them directly applicable to policy makers. They may use the proposed comparative advantages and disadvantages to identify and target policies that can strengthen potentials and relax constraints of spatial development domains. This site-specific approach may thus help them to prioritize agricultural research and development in their investment decisions, in order to reduce Uganda’s land degradation more efficiently.

Based on the stratification results developed in this paper, a spatial sampling framework was established to select 108 communities that were representative for development domains covering central, east and south Uganda. That survey region comprised more than two thirds of Uganda and excluded insecure regions in the northern and western Uganda. Intensive socio-economic survey and resource mapping procedures were performed in those communities of the survey region during the year 2000 and 2001 (Ruecker et al., 2003). The objective of those field investigations was to identify possible policy interventions to maximize the sustainability of agricultural development in Uganda. Detailed resource management aspects were investigated and soil samples were collected in each community to test the initial agricultural potential model (Ruecker et al., 2003). In parallel, IFPRI conducted detailed community and household survey in the same communities to characterize socio-economic conditions and development opportunities or constraints (Pender et al., 2001). The two data sets will be combined together at a later stage to investigate spatial relationships of natural resource and human interactions.

The information of this GIS-based stratification has been directly integrated in a follow-up nation wide IFPRI project sponsored by USAID to assess strategic land use options for Uganda and was presented at the CGIAR Annual General Meeting at the World Bank (Wood, 2001).

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