SMALL Savannah : an information system for the integrated analysis of land use change in the Far North of Cameroon

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Summary of the thesis

Problem and objective of the study

Like many environmental systems, land use systems are very complex. The complexity of these systems stems mainly from the existence of spatial and temporal dynamics, the combination of a large number of interactions and cross-scale processes. A better understanding of these interactive linkages is of great importance for the sustainable development of rural communities as this is a preliminary step in the development of management and decision support tools. The scientific community involved in environmental change studies is increasingly aware of the necessity to develop a more integrated approach and to elaborate appropriate tools for the analysis of the complex and dynamic interactions between land use changes and their biophysical, socio-economic and political driving factors. As a consequence of increasing environmental problems, there have been a growing number of international projects with the objective to develop Information Systems (IS) in various domains of environmental management, where information is crucial for decision making processes. However, methods and techniques that were designed for more simple applications are not appropriate to the requirements of Environmental Information Systems (EIS). The Far North of Cameroon is an example of central African savannas regions where an important number of agrarian landscape changes were observed as a consequence of a rapid increasing population with important human and animal mobilities. Theses changes have led to land saturation with more important competition between land types and conflict between actors. A key to sustainable development in this context is to identify which strategies will prevent the actors involved in land use and management from the natural resource degradation and poverty spiral.

The objective of the present thesis is to specify and develop SMALL Savannah, an example of Environmental Information System, designed for the integrated analysis of theses changes in view of the exploration of land use change trajectories in the near future. The specific objectives of this EIS are: 1) to characterize at different scales the main land use changes in the region during the last two decades. 2) to identify the potential driving factors and quantify their relations with land use patterns and changes and 3) to build an integrated model for the simulation of land use dynamics and the exploration of scenarios for future changes. This thesis contributes to the definition and specification of the structure of EIS seen as a preliminary step for any attempt toward the proposition of an appropriate analysis and design method **(chapter 1).**

Approach and methodology of the study

The complexity of land use systems requires appropriate methods for their analysis and understanding of ongoing processes. However, existing approaches and models used for land change analysis are often influenced by disciplinary traditions and provide incomplete explanations of land processes. To reach the objectives stated above, this thesis proposes an interdisciplinary and integrated approach that combines spatial analysis techniques and system theories with dynamic modelling in order to capture key characteristics and the complex nature of agroecosystems. System theory provides appropriate concepts to characterize the structure of agrarian systems and to represent their dynamics. Spatial and system analyses are used to integrate spatial knowledge with those provided by traditional approaches using socio-economic and historical surveys, where the emphasis is placed on relations between actors and land use at a local level. Integrated modelling and dynamic simulation of land use is seen as an appropriate scientific approach for a better understanding of the functioning of these systems and the exploration of different pathways of land use change (**chapter 2)**.

Data needed for the representation of these environmental phenomena, are heterogeneous and require the combined use of a wide range of tools and models for their storage, processing and analysis. Land use change at regional scale were analysed by combining direct observations, remote sensing and GIS to better understand landscape organisation and monitor it evolution. Statistical analysis tools were useful to identify the major land use drivers based on actual trends and comparisons of data series. A

modelling and simulation platform was used to explore land use change trajectories and provide key information for decision making **(chapter 3)**.

The SMALL Savannah Environmental Information system developed in this thesis is based on a multi-scale framework that takes into account scale effects, cross-scale observation and analysis. The identification of appropriate scales for data representation and the development of multi-scale approaches are crucial issues in ecosystem studies. The multi-scale framework described in **chapter 4** emphasises the different levels of analysis and the corresponding dominant land use change processes or issues. Relations between available data and representation scales are also discussed and a review of different methods for changing scale and undertaking cross-scale analysis is proposed. The approach used to develop SMALL Savannah covers the three main phases of existing IS development methods namely the preliminary analysis of the real system, the design of the organisational and computerized Information System and the implementation of applications.

Preliminary analysis of the land use system and design of the EIS

The study area is a small region in the Far North of Cameroon, and part of the savannas areas of Central Africa. The region is characterised by high demographic pressure combined with increasing human diversity and mobility that have induced many changes in the land use system of the study area during the past two decades. In **chapter 5**, we present an overview of the main land cover types and land use changes that have occurred in different agro-ecological situations. The demographic pressure has led to extensive land use that has resulted in increasing land saturation and competition between land use types and conflict between actors. In most cases, farmers respond to land saturation by migrating to more productive land, confirming a Malthusian perspective. The relative stability in land use indicates the high resilience of savannas ecosystems. Few intensification signs in the sense of Boserup are emerging but the real agrarian transition is still expected. The model further assumes that future trajectories will depend on the investment that local and urban actors will allow to improve land quality and management.

The SMALL Savannah Information System developed in this thesis, is designed in this context in order to analyse theses land use dynamics and to explore scenarios for future evolution. SMALL Savannah is a set of concepts, methods, tools and data used to explore land use dynamics with reference to environmental and development issues faces by rural communities of the study area. It is an example of EIS that combines 1) an observation and spatial analysis module based on a GIS for the representation of phenomena from various data sources, 2) a diagnosis module based on the synthesis of various information sources for the characterisation of the structure and functioning of the agrarian system; 3) a prediction module based on a statistical package for the explanation of land use change pattern; and 4) a dynamic modelling and simulation module for the exploration of land use change trajectories geared toward a sustainable management **(chapter 6).** The four last chapters of this thesis are devoted to four application examples that illustrate more or less the implementation of each module.

Implementation of the SMALL Savannah EIS

The spatial analysis of the recent expansion of dry season sorghum in the study area presented in **chapter 7** is an application that illustrates the ongoing land saturation processes observed in the region. Dry season sorghum is a food crop, which plays an important role in maintaining food security in the savannah area in the far North of Cameroon. During the last two decades, there has been an increasing interest of producers for this food crop which led to extensive land use practices with remarkable consequences on the sustainable management of different land uses. SMALL Savannah is used as a conceptual framework and a tool for analysing the causes and consequences of this dynamic. The crop has reinforced its position in traditional production areas and has expanded into new areas where it was not produced in the past. This recent extension has mainly been driven by an environment, which offers favourable growing conditions and generates a high demand for food in a context where food security remains uncertain. The large scale land clearing and the reduction of fallows has led to an

important destruction of woody vegetation, soil degradation and a reduction of pasture availability. The crop's expansion has also encouraged land renting and speculation, in the production and commercialisation process. Actor's strategies to face the ongoing changes vary according to local context but the most observed response is mainly dominated by extensive land use practices and food subsistence as the main production motivation. However, there are emerging signs of intensification characterised by a beneficial integration with livestock and the increased involvement of urban actors. The regional agricultural context favours a more important role of dry season sorghum in the land use system. Predicting the impacts associated with its future expansion is a key to the development of the region. This requires a detail understanding of land tenure rules, land use strategies and interactions between all the actors involved.

In this perspective, the location and accurate measurements of changes in land cover are very important for evaluating land use dynamics and a better understanding the underlying processes. However, this information on land cover is often very difficult to obtain with traditional survey methods for relatively large areas and extended periods of time. In **chapter 8**, the Environmental Information System SMALL Savanna is used as a tool for the observation and spatial analysis of land cover change in the region around Maroua, Far North of Cameroon. A diachronic and multilevel analysis is carried out, using a couple of satellite images from 1987 and 1999. Land cover patterns were derived following an approach that combines automatic image analysis with photo-interpretation. The most recent map was validated using GPS data gathered from field visits; corrections were made based on identified errors. Change analysis with GIS indicates an important decrease of the woody savannas area (-31%) which is replaced by cultivated area consisting largely of dry season agriculture (+44%) and rainfall agriculture fields (+36%). Recently, bare and often degraded land appears to be reclaimed for agricultural activities (-39%). There is an increasing scarcity of fallows and the total area where woody vegetation has recovered is extremely limited (4%). Local analysis helps to get more insight in the diversity of land use change and to explicit actor's strategies to face ongoing changes. Appropriate suggestions for land use management and planning can be derived from the results of our analyses.

The knowledge of quantitative relationships between land use patterns and biophysical as well as socioeconomic driving factors is also an important step in building dynamic GIS-based models. More often, the choice of variables to include in these models is difficult due to the complexity of the system and the underlying processes. **Chapter 9** describes the implementation of a method combining inductive and deductive approaches to identify the most pertinent sets of factors that explain land use patterns and change in a region around Maroua, Far North of Cameroon. Land use and driving factors data were derived from the SMALL Savannah EIS database. Spatial analysis is used to calculate variables that better represent the land use processes. The procedure of variable selection is based on a logistic regression model. A predictive model of land use pattern and change between 1987 and 1999 was built for each of the 6 land use types considered in the region. Results confirm the strong influence of the main urban centre and reveal that of soil suitability on land use types. Population pressure evaluated as a population potential index, explains land use patterns and changes more adequately than population density. This study has provides key elements for understanding the land use system of the study area. Quantitative information derived from this application is used to build a model that simulates spatial dynamics related to different trajectories of land use change.

Dynamic spatial models are important tools for the study of complex systems like environmental systems. Beside, an integrated approach is required in order to obtain a more comprehensive understanding of the behaviour of these systems. **Chapter 10** describes the basis of an integrated model developed to explore land use change trajectories in a region around Maroua, Far North of Cameroon. The model simulates competition between land use types taking into account a set of biophysical, socio-demographic and geo-economics driving factors. The procedure for allocating changes in the model combines the results of the spatial analysis and prediction modules of SMALL Savannah EIS. The model validation was carried out for the period 1987-1999 and the simulation of change was performed for the period 1999 -2010. Three scenarios were formulated based on the main observed trends of change and hypothesis related to land use transition as stated by Boserup and

Malthus. The major observed land use dynamics are related to the recent extension of dry season sorghum and the development of horticulture that induce more competition on land between actors and for the different land use types. The model developed constitutes an efficient knowledge support system for exploratory research and land use planning. It can also be used to initiate any concertation or negotiation between actors concerned with land management.

Concluding remarks and prospects

In this research, the case of land use system in the far North of Cameroon was used to illustrate the definition and specification of the structure of Environmental Information Systems. This region is an example of central African savannas regions where an important number of agrarian landscape change were observed as a consequence of a rapid increasing population with important human and animal mobility. The SMALL Savannah Information System developed in this context is a set of concepts, method, tools and data that can be used to characterise land use patterns and to explore trajectories of changes, in reference to environmental and development issues faced by rural communities in the study area. The relevance of this research is twofold: scientific and substantive (**chapter 11**).

Scientifically, the descriptive models presented in this thesis exhibit the complex properties of land use systems that are used as guidelines for propositions related to the adaptation and enrichment of existing Information Systems development methods. A number of methodological conclusions and research perspective can be drawn from this research. We argue that space is an important characteristic of environmental system as it supports almost all land use processes. The design and implementation phases of an EIS should include appropriate approaches to explicitly take into account the spatial component of the studied processes. An important challenge in this perspective is the linkage between social phenomena and the underlying spatial dynamics. Scale issues are very important and can be found in almost all environmental applications. A particular attention should be paid to scale issues during the different phase of the development of an EIS. The major questions are related to the identification of appropriate scales for the representation, observation and analysis and also to implementation of cross-scale analysis that can improve our understanding the process studied. Modelling and dynamic simulations appear to be of great importance in life cycle of an EIS. A modelling step should be included in the different phases of an EIS design and implementation. Given the diversity and complexity of environmental data, the storage, processing and analysis require a wide range of specialised software like GIS, DBMS, image processing or statistical packages, expert systems, simulation platforms, etc. The design and implementation of EIS should integrate these tools in a common environment. The implementation of SMALL Savannah shows that many tasks require a human expertise to interpret results and operate choices for the following tasks. The integration of software applications and the development of interfaces for EIS require a preliminary analysis to identify priority needs for communication between software applications and to specify structure for data exchange and software components in charge of data control and storage.

On an operational point of view, the developed EIS provides useful information and knowledge that help to 1) improve our understanding of land use process; 2) explore scenarios of future evolution; 3) establish the basis of land use planning; and 4) prepare the negotiation between actors involved in land management. The main land use changes in the study area are the result of demographic pressure combined with the diversity and changes of human population. Agricultural expansion appears as a central process with important interactions with changes in other land use like firewood supply or animal breeding. Protected areas are also depending on these agricultural changes. In particular, dry season sorghum appears to be an essential component of the land use system of the Far North region of Cameroon. It plays an important role in maintaining food security and it greatly influences the dynamics of other land uses. The regional agricultural context favours a more important role for this crop in the land use system. Research and concrete actions need to be carried out to monitor the expansion process and mitigate its negative impacts. Results of the quantitative and spatial exploration of land use drivers reveal that the accessibility to the main urban centre, soil suitability on land use types and population pressure evaluated as a population potential index, explains land use patterns and changes more adequately than population density. The detail knowledge provided by this analysis can

be used to guide the formulation of research hypothesis in any specific study. Concretely, it is important for any development project to know under which conditions different land use are establishing. This characterisation of the land use system according to biophysical, socio-demographic, geo-economic and political conditions is of great importance for the implementation of management and decision support tools. The simulations carried out for the period 1999 to 2010 show areas where changes are likely to occur, providing the possibility to evaluate the spatial impact of a given land management policy. The database on land use and its potential driving factors should be extended to other themes and updated in order to support research and development projects.

The simulation model developed is an appropriate tool for a regional monitoring system of land use changes geared towards a more sustainable development of rural communities. Potential users are scientists and actors involved in land use planning for decision-making and adaptive management of land. Additional utilisation should be considered by local actors to discuss and prepare any dialogue or negotiation when dealing with participatory approaches of land use and management. The simulation model can be used by scientist working in the study area to test hypothesis on the possible land use change trajectories. Future research should focus on the development of an individual-based modelling approach that would better address actor decisions, their land use strategies, social networks and their interactions. The development of a multi-agents model and its integration with the existing GIS is a promising perspective in this respect. SMALL Savannah is an example of application that highlights important issues related to the design and implementation of Environmental Information System. Results from this case study provide guidelines to adapt and enrich the existing Information Systems design method.