Integration of Local Participatory and Regional Planning for Resources Management Using Remote Sensing and GIS

Laurent G. Sedogo

Promotors Prof. Dr. Ir. Eric M.A. Smaling
Professor of Soil Inventarization and
Land Evaluation, Wageningen University

Prof. Dr. Andrew K. Skidmore
Professor of Vegetation and Agricultural Land Use Survey,
ITC, Enschede

Co-promotor Dr. Susanne M.E Groten
Assistant Professor, ITC, Enschede

Examining Committee:

Prof. Dr. A. Gouro	CIRDES, Burkina Faso
Prof. Dr. Ir. A.K. Bregt	Wageningen University
Prof. Dr. Ir. J.D. van der Ploeg	Wageningen University
Dr. M.K. McCall	ITC, Enschede

Integration of Local Participatory and Regional Planning for Resources Management Using Remote Sensing and GIS

Laurent G. Sedogo

Thesis
To fulfill the requirements for the degree of doctor on the authority of the Rector Magnificus of Wageningen University, Prof. Dr. Ir. L. Speelman to be publicly defended on Friday 22nd November 2002 at three o'clock afternoon
in the auditorium of ITC, Enschede

Doctoral thesis (2002) ISBN 90-5808-751-4
Wageningen University, The Netherlands

ITC Dissertation No. 92

This study was carried out at the International Institute for Geo-Information Science and Earth Observation (ITC)

P.O. Box 6
7500 AA Enschede,
The Netherlands

To my late Father and to my Mother

To Jean Pierre and Mary

To Christine, Anny, Fabrice and Fabien

Acknowledgements

The completion of this thesis would have not been possible without the support and cooperation of many individuals and institutions. I am very grateful to all of them.

I am greatly indebted to Dr. Susanne Groten who motivated me to undertake this Ph.D study and made possible my coming at ITC. Throughout this period, I have been fortunate to receive constructive criticism and guidance from her. Susanne was very supportive in all aspects during the entire course of my study at ITC. Her rich knowledge in the field of participatory GIS and her experience in the domain of natural resources management in West Africa and particularly in Burkina Faso have had a great contribution to this thesis. Susanne, I have really appreciated your patience and friendship.

I wish to thank Prof Eric Smaling for spontaneously accepting to promote my study. He promptly reviewed many of my chapters and guided me through out the structuring of my book. His comments and suggestions on the structure and contents of the thesis have considerably improved its quality and readability. I learned a lot from his style of supervision and I really benefited from his knowledge and long experience in land use planning and especially the agricultural problems in Africa.

I am very grateful to Prof Andrew Skidmore for his support and encouragement. We had quite a number of stimulating scientific discussions. I really appreciated his rigorous scientific guidance that he provided to me with a great simplicity. I also benefited from the Ph.D. tutorial program that he introduced at ACE Division. The different topics that have been discussed during these tutorials helped me a lot to sharpen my views and thoughts in many aspects.

Many thanks to Dr McCall for all the nice discussions we had, and his support and assistance with chapter 6 of the thesis. Many thanks also to Henk van Oosten for his assistance in the development of the expert system, for his simplicity and friendship.

I am thankful to Prof. Molenaar and Drs Johan de Meijere who, during my MSc study, introduced me into the domain of Geo-information Science and gave me a real interest for scientific and technical uses of GIS for rural development in my country, Burkina Faso.

I am very thankful to Father Franz Balemans with whom I have intensively worked in the frame of LUCODEB, a desertification control project in Burkina Faso. Not only did he open his heart to me and to my family in Burkina Faso, but also he introduced me into the homes and hearts of all his brothers and sisters, and all the other members of the Family Balemans here in the Netherlands. Never did I feel lonely over all these years, as I felt to be a complete member of the family, sharing all events of their life. Especially I am very thankful to Will Kavelaars, her sons and daughters, and their respective families, for all their attention and kindness. I am also grateful to all the other wonderful Dutch friends I have made over these years.

Especially, I am thankful to Jan Vervoort and all his family for all the nice moments we shared during these years. Many thanks too to the Janssens and the Wildenburgs.

I wish to thank all other people and institutions who, in one way or another supported or helped me during my study. In particular, ITC research program for the financial support and all the facilities provided to me during these years. I thank also my employer the Ministry of Environment in Burkina Faso. In particular I am grateful to the Permanent Secretary of the CONAGESE who allowed me to undertake this study, and the Director of the PNGT Program for the technical and material support during my fieldwork in Burkina Faso. My many thanks also to the staff of the PNGT project in Bobo-Dioulasso, in particular to Mouhamed Drabo for his help and friendship.

I sincerely wish to thank all my colleagues PhD students, with whom I shared very important moments during these years: Elisabeth, Karin, Amon, Mohamed, Onismo, Chaichok, Martin, Citlali, Grace, Yelle, Etien, Uday, Santos and many others that I could not list here. Many thanks for the good company, moral support and friendship. I thank my country mates, Elisabeth, Jean and Rahim for the good company and moral support.

Much gratitude to the members of my family for all the moral support they gave me during my study. My late Father, my Mum, Jean Pierre and Mary, thank you for the education you gave me; thank you Michel for being my ' spiritual scientific guide'; thank you Pathe, Susanne and all other brothers, sisters and relatives. Many thanks also to my old friends: Jean Claude, Halidou, Charles, Gilles and their respective families. Although I have been away from you, you have kept me in your heart.

I would finally like to thank Christine, Anny Claude, Anicet Fabrice and Fabien Yannick for their love, patience and sacrifice. By no means I could ever repay you. This thesis is yours and you should know that it could have never come into, without you being my source of inspiration and encouragement and without your love.

CONTENTS

I. TOWARDS A BOTTOM-UP APPROACH IN LAND USE PLANNING

II. DEFINITION OF LAND MANAGEMENT UNITS IN PARTICIPATORY LAND USE PLANNING USING PRA AND GIS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

TOWARDS A BOTTOM-UP APPROACH IN LAND USE PLANNING

1.1 Setting the scene: Land use and land degradation in Burkina Faso

Burkina Faso is a landlocked country covering an area of 274,000 square kilometres. Located in the centre of West Africa between 5^{o} W - 2^{o} E and 10^{o} –15^{o} N, it lies entirely in the Sudano-Sahelian agro-ecological zone. With a GDP per capita of US $210 in 2000 (World Bank, 2002) and very low human resource indicators, Burkina Faso ranks among the world's poorest nations[1]. Agriculture is the dominant sector of the economy. It employs more than 80% of the total population estimated at 10,312,600 in 1996 (INSD, 1988). In 2001, the agricultural sector generated 76% of exports (57% for cotton and 19% for livestock products respectively). Agricultural development and rural land use planning have always been key issues in the economic development agendas of the country since its independence in 1960. Improving the performance of the sector should not only contribute to food security and rural poverty alleviation, but also to fostering economic growth. However, while the sector has mobilized a considerable part of the country's international aid and loans, 51% of the rural population lives below the poverty line[2] (World Bank, 2000a). The manifold re-orientations of the intervention strategies during the past four decades reflect the inability of decision-makers to promote sustainable development within the local ecological and socio-economic constraints.

These constraints include very fragile ecosystems, which are in general subject to erratic rainfall regimes. The soils are generally shallow and poor, with a seriously deteriorated structure and low organic matter and nutrient contents (see for details UNDP-FAO, 1980; Sivakumar and Gnoumou, 1987; Smaling et al., 1990; Kessler and Geerling, 1994). In many places, the drastic reduction in vegetation cover has exposed the soils to severe water and wind erosion hazards (Stroosnijder, 1994; Rietkerk, 1998; Stroosnijder and van Rheenen, 2001). The socio-economic factors are also very unfavourable, showing a strong population growth rate of 2.8% per year, which was until recently higher than the economic growth rate (2.6% per year during the period 1965 – 1986). The agricultural sector's share of the GDP, which was 53% in 1965, has now declined to 35% (while the services and industrial sectors represent respectively 48% and 17%). Despite this decline, the rural economy still contributes more to the exploitation of natural resources. The high population density (more than 80 inhabitants per km^2 in some areas) puts important pressure on the arable lands (nearly 9 million hectares for a rural population of 8.7 million).

Land use and natural resources management are strongly influenced by the traditional tenure regimes (UNSO, 1994; Gray and Kevane, 2001; Pare, 2001). The major land use systems are mostly extensive, and the low investment capacity of the rural population together with the absence of real stimulation policies are often cited as the main obstacles to agricultural intensification (IOV, 1994; PAGIFS, 1998). The local strategies aiming at increasing cereal production (to meet the needs of a growing population) are mostly based on the expansion of the cultivation areas, resulting in important nationwide

1 169 among 175 countries based on UNDP Human Development Index in 2002
2 Estimated at a threshold of US $1 per day. The incidence is higher among subsistence farmers (77%) than commercial farmers (42%). This percentage is much lower among the urban population (16%).

deforestation. Population growth and poverty are said to be the driving forces of the environmental degradation, which further leads to the deterioration of socio-economic conditions. A study of the World Bank in 1990 found that the degradation cost represented 4% of the GNP (IOV, 1994). Recent studies tended to prove that the environmental degradation has been in general overestimated in some areas, due to an underestimation of the local coping capacities (Howorth and O'Keefe, 1998; Gray, 1999; Mazzucato and Niemeijer, 2001). However, for lack of adequate responses to the environmental problems, the threshold of degradation has been surpassed in many places where the cultivable lands could no longer be extended, causing the fallow practice to be abandoned and even marginal lands to be used. Because very little input of chemical fertilizer is used (around 8 kg of cotton complex and 3 kg of urea per hectare annually (PAGIFS, 1998), the soils are being rapidly mined. This situation in the central plateau has contributed to an important migration towards the west, south and east of the country, as well as the coastal neighbouring countries[3].

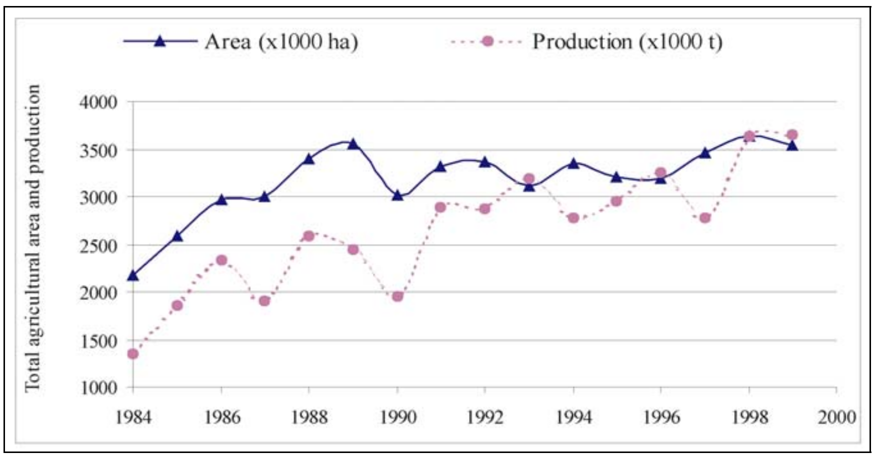


Figure 1.1 Evolution of cultivated lands and agricultural production between 1984 and 1999 (Source: national agricultural statistics)

These facts, more than ever before, bring the issue of land use planning and natural resources management in Burkina Faso, and more generally in Sahelian countries, back to the core of the rural development agenda. The objectives of agricultural development determined through the central decision-making processes at the earlier stage of political independence in the 1960s are still relevant today. Yet the overall aim of the agricultural production has shifted from raising funds for the state to satisfying the people's own basic needs. During the last decades, the attention of the international community for the

3 Research carried out by the Antenne Sahelienne of the Wageningen Agricultural University in the provinces of Sanmantenga and Zoundweogo (Central Plateau of Burkina Faso) showed that not less than 32% of the young men were involved in migration (de Graaf et al., 2001)

Sahelian countries was focussed on poverty alleviation, increasing food sufficiency, stemming migration and combating environmental degradation (Shaxson et al., 1997). The concern for environmental policy also strongly influenced agricultural development policy. Until recently, the driving forces behind environmental policy were powerful, widely perceived images such as erosion, land degradation and deforestation. However, farmers were not only perceived as victims but also as agents of degradation and many proposed solutions were based on the premise that stewardship over natural resources was the responsibility of the state (Leach and Mearns, 1996).

Since the publication of the Bruntland report (WCED, 1987) and especially the Agenda 21 (UNCED, 1992), the attention of scientists and policy-makers has been drawn towards the concept of sustainable agriculture (Faeth, 1993; Farshad and Zinc, 1993), putting the rural communities at the centre of the land use planning and land management cycle (van Keulen et al., 2000). Therefore, and in accordance with economic liberalization and democratization processes started in the 1990s, new decentralized approaches to development planning have been promoted. Among those is the *Gestion de Terroirs* approach (Lewis, 1996; UNSO, 1994) that has developed over recent years in Sahelian West Africa as a means of addressing rural development through participatory land management activities.

In this new setting, an approach to study land use planning problems that breaks with the classical methods and tools should be considered. This research is an attempt to address participatory land use planning issues in a systematic way, compatible with known decision-making tools such a geographic information systems (GIS). In particular, it aims at harmoniously bridging the gap between the local and the regional levels, and formalizing a framework for bottom-up land use planning.

1.2 Development of land use planning approaches

1.2.1 Definitions of land use planning

The literature proposes different definitions for land use planning (LUP), which portray the evolution of the concepts and methods used. For instance, Dent (1988; 1993) defined LUP as a means of helping decision-makers decide how to use the land: by systematically evaluating alternative patterns of land use, choosing that use which meets specified goals, and drawing-up policies and programmes for the use of the land. One of the most quoted definitions is that of Fresco et al. (1992), which defines land use planning as a form of regional planning, directed to the best use of land in view of accepted objectives, and of environmental and societal opportunities and constraints. But as noted by Mohammed (1999), all the terminologies associated with these definitions of land use planning mostly agree to consider and interpret the activity as a central decision-making process. Therefore, land use planning has for a long time been seen as a static top-down exercise, generally resulting in a process in which planners tell people what to do. The call of Agenda 21 for an integrated and a more land users-centred approach (UNCED, 1992) has resulted in a re-definition of land use planning as a decision-making process that facilitates the allocation of land to the uses that provide the greatest sustainable benefits (FAO, 1995). With regards to the concept of sustainability, the function of land use planning is to guide decisions on land use in such a way that the land resources are put to the most beneficial use for man, while at the same time conserving those resources for the future. Providing good information related to people's needs and perceptions, the physical potential of their natural resources and the possible environmental impact of alternatives is a prerequisite for a successful land use planning process. Herein, land evaluation (LE) played an important role as a means of assessing land performance when used for specified purposes (FAO, 1976), or as a method to explain or predict the use potential of land (Van Diepen et al., 1991).

1.2.2 Land evaluation and land use system analysis as tools for land use planning

The primary designation of LE was to be applied by a multidisciplinary group of specialists from natural sciences as a methodological tool to provide a scientific evaluation of land for agricultural purposes. This group includes disciplines such as soil science, agronomy, agricultural engineering, climatology and geomorphology. LE delivers tools for strategic land use planning (LUP) as it allows thorough diagnosing of a land use system, while LUP is used for a complete design of the land use system. In the 1970s and 1980s, both disciplines evolved strongly along the lines of the biophysical frameworks developed by FAO (1976; 1985), assuming a substantial degree of linearity between LE and LUP. While land use systems were supposed to be designed on the basis of the suitability assessment of land utilization types (LUTs), the evaluation remained quite qualitative (Beek et al., 1996). Little attention was paid to the socio-economic environment in the evaluation and planning processes. The later land use system analysis (LUSA) (Driessen and Konijn, 1992) allowed LE to be turned into a more quantitative exercise. It also made it possible to bridge both the biophysical and socio-economic dimensions in a holistic view of a land use system, and to create clear pictures of trade-offs between economic, environmental and societal goals. Meanwhile, there has also been an attempt to link LE and farming system analysis (Conway, 1985; 1987; Fresco et al., 1990; 1992) for a more land user-oriented approach to planning, by adding inputs of socio-economic data collected through rural rapid appraisal (RRA) (Chambers, 1980). The essence of such approaches was to meet some of the criticisms against both approaches while benefiting from the strengths of each (Mohammed, 1999).

1.2.3 Land quality indicators (LQIs) for sustainable land management

As noted by Beek et al (1996), placing LE and LUSA in the broader context of LUP revealed a potential conflict between technology-oriented land resource specialists concerned with the present and future performance of the land, and the social scientist concerned with the land users and their well being. Dumanski and Pieri (2000) noted that sustainable land management and the choice of feasible and cost-effective management options are hampered by the lack of available indicators for monitoring how the farmers manage their land, the impact of policies and programmes on land management choices, and the impact of different scenarios on land quality. The challenge was to meet the requirement for increased agricultural production and intensification while maintaining and enhancing the quality of land resources on which production depends. Therefore beyond the concept of land quality proposed by FAO (1976), there was a need to define land quality indicators (LQIs), as thresholds and standards upon which to measure and assess progress towards these goals. The framework for the evaluation of sustainable land management (SLM) (Smyth and Dumanski, 1993) was proposed as an “after Rio” response to the demand for these indicators. It makes it possible to monitor the state of natural resources, the pressure exerted on them and the responses necessary to safeguard the productive potential or other values of the land. The basis for evaluating SLM was to a great extent derived from LE, complemented by the social, economic and ecological dimensions.

1.2.4 SLM in practice: the limits of the hard systems approach
Hurni (2000) quoting Bouma (1997) has identified three major development components of SLM: technology, policy and land use planning. Herein a systems approach gives better insight into the concept of SLM, as a change in one aspect necessarily affects the others. Land use planning stops being the “end-process”, which different methods, tools and disciplines should contribute to. On the contrary, land use planning becomes more a process by which the land users move on the way towards sustainable development, by controlling the basic mechanisms and steps (van Keulen, 2000). Yet, the traditional hard systems approach underlying the development of agricultural systems is limited with regards to these components of SLM mentioned above. The traditional tools and methods used so far for agricultural development planning create bottlenecks at the macro and the micro (farmers) level of the decision-making process:

- The macro level determines the policy measures used to support agricultural development. The tools used are mostly based on linear or “knowledge-power” models, which in essence generate top-down decision-making. They also strongly emphasize mobilizing discourses on soil erosion, deforestation and so on (Keeley and Scoones, 1999), which often run counter to farmers’ concerns. Pretty (1998) noted also that most policy measures act as powerful disincentives against sustainability because they do not reflect long-term social and environmental costs of resource use.

- At the farmers’ level, it is undeniable that innovations are necessary to ensure a transition towards sustainable agriculture. However, the efforts for the adoption of improved production technology through top-down methods such as transfer of technology (ToT) models (Oakley et al., 1991) did not produce the expected results. The later farming system research (FSR) and other related methods focussed also on a linear top-down progression, from problem formulation and opportunity diagnosis to technology design, adaptation and verification. These methods failed to break the boundary between the researchers / extensionists and the farmers (Scoones and Thompson, 1994) and to consider the land-users as the focal agents.

1.3 The bottom-up approach to LUP

1.3.1 The soft system methodology: a framework for a new development paradigm
During the last decades many authors underscored the need to include more social science in development (Cernea, 1991; Scoones and Thompson, 1994; Röling and

Wagemakers, 1998). In the context of sustainable development, views of agricultural systems based on the concept of agro-ecosystems (Conway, 1987; Ikerd, 1993) have to be turned into more social constructs approaches (Toledo, 1997; Röling and Wagemakers, 1998). Therefore, a holistic approach, which focusses on the knowledge of the rural communities, is required to address land use and agricultural development problems.

"Systems thinking" or "soft system methodology (SSM)" (Checkland and Scholes, 1990) was introduced as a necessary holistic approach to address ill-structured problems. In the SSM, a system should be developed for an organization as a whole, and should include the social interaction of the participants. This methodology concentrates on providing a mechanism for human interaction that will ultimately lead to the resolution of problems. Soft system methodology is more adapted to the social and management sciences as compared to traditional natural sciences, where methods usually break up a problem into smaller and less complex parts and provide a solid theoretical framework for knowledge elicitation. Apart from business and engineering applications, soft systems are increasingly being used in agricultural development and environmental management because of the inherent complexity of natural resource issues (Röling, 1997; Röling and Wagemakers, 1998). Together with being a learning system in relation to complex and problematical human situations (Checkland and Scholes, 1990), SSM uses visualization tools to describe the real world problem as perceived by the users. It is similar to the practice of participatory rural appraisal (PRA) (Scoones and Thompson, 1994) used to support participatory development planning.

1.3.2 Participatory approaches in land use planning (LUP)

The history of the approaches to development thinking from the 1950s onwards shows an evolution from the idea of "trickle down economics" towards more participation of the people in the interventions (Oakley et al., 1991; Cowen and Shenton, 1996; Vainio-Mattila, 2000). The principle of participation was first explored as a need to include local views and indigenous knowledge into research and extension agendas (Freire, 1972; Chambers, 1983; 1989; Scoones and Thompson, 1994). People's active participation was recommended in the mid-1970s to address the growing awareness that development efforts were having little impact without the active participation of people in rural programmes. The notion of active participation herein takes a significant importance, and differs from the early understandings of the concept. At the earlier stage of its implementation, participation was mostly seen as people's involvement in the implementation and evaluation of the programmes and projects for enhancing the chances of success (ECLA, 1973; Cohen and Uphof, 1977). It has also been considered as an organizational framework contributing to the emergence of rural organizations and co-operatives used to carry out development programmes (Oakley et al., 1991). It has been implemented for many applications in both rural and urban sectors all over the world, including education, health-care and natural resource management (Hadi, 2000; Dirorimwe, 1998; Gasteyer, 2000).

However, participation seen as “empowerment” is considered to be the steering system of actual participatory development models (Oakley et al, 1991, Vainio-Mattila, 2000; Cowie, 2000). In this setting, endogenous mechanisms and methods allow the land-users to take control of their development processes. Responsibility and decision-making are truly shared and success is measured not by returns, for either stakeholders or donors, but by the evaluation of the stakeholders and participants themselves. Many tools are available for participatory development practitioners, promoting learning and communication based on interaction between parties, and a mutual sharing of experience and knowledge. Among others, participatory technology development (PTD), participatory action research (PAR) and participatory rural appraisal (PRA) proved their efficiency to support participatory processes (Scoones and Thompson, 1994).

Participatory rural appraisal is used to describe a family of methods that enable local people to share, enhance and analyse their knowledge of life and conditions to plan and to act (Chambers, 1994a) It flows from and owes much to the tradition and methods of participatory research (e.g. Freire, 1972), applied anthropology, and field research on farming systems (Gilbert et al., 1980; Shaner et al., 1982). It has evolved most directly from a synthesis of agro-ecosystem analysis (Conway, 1985; 1987) and rural rapid appraisal (RRA). Different methods have been successfully developed, tested and implemented with local people. These include participatory mapping and modelling, transect walks, matrix scoring, well being grouping and ranking, institutional diagramming, seasonal calendars trend and change analysis and analytical diagramming. PRA has been used in natural resources management (e.g. soil and water conservation, forestry, fisheries, wildlife community planning, etc.) agriculture, health and food security, etc. In Burkina Faso, PRA is used to support local participatory land use planning. It is largely the toolbox that serves as a strong basis for the implementation of the *Gestion des Terroirs* approach.

1.3.3 Brief history of land use planning in Burkina Faso

Three main periods can be used to characterize the evolution in rural development and land use planning in Burkina Faso. The first period spans the colonial post-Second World War era to the mid-1960s. During that period the population had to achieve constraining and top-down objectives of producing cash crops (mainly cotton and peanut) through French institutions such as CFDT[4] and IRHO[5] (Yonly, 1997). This production was first used for the needs of the colonial administration and later as the main income provider for the new independent state.

The second period running from the mid-1960s to the mid-1980s was characterized by a willingness to reorient the development goal and planning objectives towards the satisfaction of people’s needs. For this, regional development institutions (ORD) were created, aiming to stimulate economic development at regional level by the implementation of two main approaches to regional planning: sectoral extension development and integrated rural development (that includes different activities such as

4 Compagnie Française pour le Developpement des Textiles
5 Institut de Recherche pour les Huiles et Oléagineux Tropicaux

physical planning, illiteracy alleviation, rural credits and marketing). Rural organizations and co-operatives were created to facilitate the adoption and dissemination of new technologies, credits and equipments, and circulation of agricultural products through cereal banks. Today there are more than 10,000 registered farmers' organizations and groups (250 cooperatives and 10,627 preco-operatives), in addition to groups that were formed informally for sectoral extension and other purposes. They hardly played an active role in planning, implementing or evaluating the programmes and projects, even though experiences of local initiatives (e.g. *Groupements Naam*) or NGOs proved to be successful for improving conservation strategies and technology adoption.

During the last period from the mid-1980s onwards, the failure of the top-down approaches was recognized. Despite strong endogenous economic and environmental policies and a slight increase in agricultural investment between 1984 and 1988, the effects of the successive droughts and the strong population growth have seriously undermined the agricultural development. This has led to the withdrawal of the government from direct interventions in the rural sector under the pressure of external policies such as the Structural Adjustment Program (SAP). The extension of the SAP to the agricultural sector, different liberalization reforms (the public sector, prices and markets) and a programme of decentralization implemented in the 1990s have weakened the capacity of the state to solve the main rural problem: impoverishment of the natural resources leading to growing poverty among the rural population. These arguments have resulted in proposals to delegate the management of natural resources to local communities through the participatory approach known as *Gestion des Terroirs (GT)* (UNSO, 1994).

1.3.4 The Gestion des Terroirs approach in Burkina Faso

The *Gestion des Terroirs (GT)* is a community-based land management approach, which developed and increased all over Sahelian West Africa in the late 1980s. *Terroir* is a Francophone concept meaning an area of territory claimed, managed and used by the community that lives on and derives a living from it (Capo-chichi et al., 1995; Teyssier, 1995). More than just a physical area the *terroir* is also a social construct and the notion of natural resources, the ecological capital from which communities derive their means of existence, is likewise socially defined. Today, the *terroir* is a well-established geographical concept as well as an indigenous knowledge system. The related G*estion des Terroirs* approach that emerged as a rural development methodology in Burkina Faso is promoted nation-wide by the *Programme National de Gestion des Terroirs* (PNGT). The basic elements of the programme are the following (PNGT, 1993; Engberg, 1995):

- The activities under the *Gestion des Terroirs* programme are based on the idea that natural resource management is a major problem in rural development, in addition to the construction of village infrastructure (schools, health centres, wells, etc.).
- It is acknowledged that villagers know more about their local environment than government officials, but they do not fully utilize their knowledge to carefully manage natural resources. It is therefore expected that management of natural resources will be more successful with the participation of villagers than if carried out by the state alone.

- It is recognized that there are diverse interests within the *terroir* in relation to natural resources among different social groups such as farmers and pastoralists, women and men, youngsters and elders. Therefore, participatory tools (i.e. PRA, stakeholders' analysis) should help to enhance and express the perceptions, constraints and knowledge of these groups and to support the negotiation processes at the different levels.
- The land management process is closely linked to the political and administrative decentralization processes to insure that local communities really take control over the use of their natural resources. Therefore, local planning and land management committees, which guarantee an active representation of the different groups, should be established to facilitate internal and external negotiation processes.
- Village lands should be demarcated, in order to clarify the area of which each village is in charge. A land management committee including the representatives of all groups should elaborate resource management plans based on a thorough participatory diagnosis, with the support of technicians from the relevant outside partners.

As such, this approach has introduced an upheaval in the relationships between the rural societies and their environment, by making them responsible for planning and managing their resources. With regards to the planning process, it has also changed the role of the actors in planning and the means to achieve their goals.

1.4 Towards the integration of local participatory and regional levels of planning

1.4.1 Matching local and regional planning needs

The main objective of regional planning is to improve the general living conditions of the rural people, mainly by increasing agricultural production and improving the socio-economical infrastructure (roads, schools, health centres, water points, etc.). Ambitious projects aiming to develop predefined cropping systems at regional level have been identified according to the potentialities of each region. Sectoral development plans have been adopted through pilot projects, introducing often contradictory definitions of regions. The superimposition of projects and the different approaches used were sources of conflicts, not only between the institutions, but also between the social groups benefiting from their intervention. For example, the creation of a pastoral zone in formerly cultivated and forested areas in the south and south-west generated frequent bloody conflicts between the native population and migrant herders. The implementation of regional plans revealed many other deficiencies in problem solving for local populations, such as:

- Duplication of activities of different partners in the same localities;
- Aims and goals did not match the population’s needs and expectations;
- Dissemination and misappropriation of the financial support by community leaders, politicians, and projects staff.

With the *Gestion desTerroirs* approach, regional planning should play a softer role of co-ordination and linking local plans and initiatives in harmonious frameworks. Various studies acknowledged that the approach was well received by both local and regional stakeholders and that it contributed to achieving their objectives (Van den Briel et al., 1994; Capo-chichi et al., 1995). Most donors have a strong conviction that at last, the appropriate answers to rural development problems in the Sahel have been found (UNSO, 1994). In particular, a bottom-up approach could contribute to matching local and regional planning needs. However, there are still other constraints and gaps that need to be filled.

1.4.2 Constraints in the bottom-up approach to LUP

At the local level, the *Gestion des Terroirs* approach has mobilized the efforts of researchers and policy-makers in Burkina Faso and elsewhere in Africa that resulted in operational mechanisms, tools and methods for planning with local people (van den Hoek et al., 1988; van den Hoek, 1992; Luning, 1994; Capo-chichi et al., 1995; BIT-ACOPAM, 1996). However, so far, most methodological applications of participatory planning remained too local or quite sectoral, such as in forestry management (Davis-Case, 1990) or rangeland management (Water-Bayers, 1994). In establishing the *terroir* as the basic unit of planning, the issue is how to build an integrated land use system including all the different dimensions: spatial, ecological and economic (based on the concept of the *terroir* as social construct). Heterogeneity and diversity of the local stakeholders should also be considered (Engberg, 1995), i.e., the diversity of perceptions of the different groups of stakeholders should be considered in the framework of (a democratic) representative land use plan. Herein, a horizontal problem of integration has to be solved in relation to the different dimensions of the *terroir* as a local land management system. Other problems inherent in the local level can also be mentioned, such as:

- Due to their lack of in-depth analytical capabilities, the local decision-making boards often fail to propose new alternatives for land use or management practices (e.g. how to upgrade the result of the local use planning based on the local perceptions, knowledge and constraints).
- In the context of high competition for natural resources, a global consensus on land use and management practices is sometimes hard to obtain (because clear pictures showing the impact of the different alternatives are lacking or because of conflicts of interests).
- It can be noted that the bottom-up approach does not deal with the different levels at which natural resource use takes place. However, establishing a planning framework at the broader district or regional level is an essential next step to achieving greater consistency amongst the mosaic of micro-level local plans. It is also important to address the issue of management of common property resources, and also to provide a framework for resolving secondary and tertiary rights of access to *terroir* resources (UNSO, 1994). The links between local and regional planning are not yet well developed, generating misunderstanding and sometimes conflicts between the population and regional decision-makers. Besides, the lack of co-ordination between the mass of sectoral (regional) programmes and projects is also a source of land use conflicts among the social groups at local level. Herein, the problem of scaling up can hardly be addressed in the same way as a classical aggregation problem in land use planning (Rabbinge and van Ittersum, 1994), considering the complexity of the *terroir* (which is the elementary land use system). The integration between the two levels is not a simple model-based exercise of scaling-up, but rather should aid in facilitating the dialogue and negotiations between

stakeholders. However, there is a need to combine information from different sources, which requires a different type of conceptualization, abstraction and analysis.

1.4.3 A Spatial approach combining hard and soft system concepts

As mentioned earlier, new methods of surveying and planning were introduced with the participatory approaches. Together with the set of participatory tools used for spatial information gathering and analysis, important research efforts have been made to introduce geographic information systems as local planning and decision- making tools (Abbot et al., 1998; Gonzalez, 2000; Al Kodmany, 2001; Bojorquez et al., 2001). The use of aerial photography, GPS and GIS in participatory planning and resources management is rapidly progressing (Groten, 1997; 1998). This does not mean that the use of geo-information techniques are without controversy: some consider it as a symptom of a technocratic approach, others as being too expensive, too complicated, too time-consuming or as tools that are not being mastered by local populations. Due to a lack of experience, many use them superficially, because they do not yet understand the potentials of the application.

GIS have been successfully used for spatial modelling and decision-making in land management and resources assessment (Burrough, 1986; Aronoff, 1989; Freda, 1995; Ceccarelli, 1996; Carranza, 2002) by providing, integrating and, analysing a wide variety of spatial data. However, in the participatory approach, GIS is hardly used (alone, or in combination with other computer-based systems) as support for decision-making to improve the planning process and/or to upgrade management practices. Besides, GIS has limited capabilities in some critical domains such as knowledge and uncertainty handling, and for sophisticated forms of spatial analysis in terms of knowledge representation and processing (Fischer, 1994; Goodchild, 1990; Leung, 1990). It is difficult to capture, integrate and translate into feasible plans the needs and perceptions of all social groups sharing the resources of the *terroir* using GIS and relevant analytical tools. Other important questions seek to understand: (1) how to use the participatory planning at *terroir* level as a basis for a higher level by integrating this information into regional planning; (2) how to match regional planning information needs with local information needs, surveys and planning dynamics, both in concept and in practice.

In this study answers to these questions will be explored through an information system viewpoint. As an application to a hard systems approach, structured systems methodology has been used to support the development of information systems (Shepard and Bell, 1989; de Lopez et al, 1996) and more specifically geographic information systems (Webster, 1994). However, in order to cope with the context of the social construct inherent to the *terroir,* a combination with a soft system methodology is needed. This will allow the use of the soft information collected through PRA surveys, as well as the hard data relative to the physical and socio-economic environments at both levels of planning.

1.4.4 Knowledge-based GIS and spatial data modelling

A GIS is a computer-based information system, which attempts to capture, store, manipulate and display spatially referenced data, for solving research, planning and management problems. Geographical problems in participatory land use planning are naturally complex and their solutions require an intelligent use of not only large databases, but also structured and unstructured knowledge. In decision support systems, various tools could theoretically be linked with artificial intelligence (AI) based on simple reasoning rules, fuzzy logic, or even more sophisticated forms of spatial analysis and modelling (Leung, 1992; Fischer, 1994). Linking GIS with an artificial intelligence component such as an expert system to integrate local knowledge is one way to solve some deficiencies in land use planning. An expert system or knowledge-based system is a computer system that employs human expertise to solve problems that usually require human expertise (e.g. soil quality assessment). It is also known as a computer program that contains a knowledge base and a set of algorithms (or rules) that infer new facts from knowledge and from incoming data. The knowledge base contains the expert knowledge related to the domain for which the system has been designed. For a participatory land management expert system, therefore, the knowledge base will incorporate the knowledge gathered near the population by various techniques such as PRA and interactive system analysis. The main factors influencing or affecting the local participatory land use planning and the management of *terroir* resources will be identified. These factors will be mainly based on local representation of physical features like soil, landscape, vegetation and the main socio-economic aspects identified from PRA.

The choice of the form of a knowledge representation is critical in building the expert system. The major forms of knowledge representation described in the literature are associative (semantic) networks, frames, and objects. The object form will be used in the present research, because of its adaptability to the soft system methodology environment, and the application of object-oriented concepts in spatial modelling. In a geographic context, the field and the terrain object approaches are the two main methods used in modelling spatial objects. The terrain approach chosen for the present research describes geographical objects by their static properties: object identifier, attributes and geometry, and their dynamic properties or operations (Molenaar, 1991; Suryana, 1997). The state of an object is given by its attribute values, its behaviour and by the object-specific operations that are encapsulated within the description of the object. In a spatial database, the objects are represented as points, lines and polygons depending on the mapping context (Molenaar, 1991). Data can be represented either in raster (grid cells) or vector models. Data structures are used to describe the thematic arrangement of basic objects (object classes) and the links between the geometric and thematic data. Depending on the user's context, classification of the type of relationships between spatial objects can be used to undertake spatial abstraction procedures, using object classification, aggregation or association (Molenaar, 1993). A GIS abstraction procedure involves a context transformation, which implies changes in the representation of objects through their attribute structure (classification) and/or their geometry (feature types). Modelling the *terroir* as a GIS entity supposes a conceptual definition of the spatial

objects involved during the process, and a clear description of the thematic and geometrical links between them.
This conceptual modelling will be supported by the participatory rural appraisal (PRA) as a basis for a soft system approach to understand the relationships between the land users and the different land unit classes. The interactive system analysis will complete the conceptual and logical modelling, which can be implemented in a raster GIS environment. Therefore, integrating anthropological and biophysical parameters with system-oriented approaches in a multidisciplinary and holistic framework is proposed in this research for introducing GIS as a decision-making tool in participatory land use planning and land management.

1. 5 Objectives of the study and research questions

1.5.1 General objective

The general objective of the study is to develop methods for a rational integration of participatory local and regional planning for sustainable land management using geo-information tools.

1.5.2 Specific objective 1:

To develop a method for defining and mapping the land management units relevant to all stakeholders and suitable for systematic storage in a GIS environment.

- *Q1.1 How can the local people's perception of their terroir and management units in a context of sustainable development be modelled in a GIS using PAR tools?*

- *Q1.2 Does the GIS approach to the definition of land management units coincide with or contradict the perception of local communities (concerning which resources, information, why, how)?*

- *Q1.3 What is the impact of the cultural, socio-economic and biophysical factors (internal and external) on the definition of the land management units for the different social groups?*

1.5.3 Specific objective 2:

To develop methods for integrating local knowledge and regional planning information for bottom-up regional planning purposes, using GIS and expert systems.

- *Q2.1 What is the relevance of local planning information collected from PRA for regional planning?*

- *Q2.2 Does the GIS definition of spatial units (object-oriented) coincide with or mismatch with local people's perceptions (concerning which resources, information, why, how)?*

- *Q2.3 What are the hierarchical links (functional, organisational and ecological) between local management units and regional planning units?*

1.5.4 Specific objective 3:
To develop methods for addressing critical issues in sustainable land management, such as degradation assessment and conflict management, at regional level using both local knowledge and regional planning information.

- *Q3.1 Is a Bayesian approach suitable for local knowledge representation? Can it integrate the perceptions, goals and expectations of local people into regional planning, using a knowledge-based system?*

- *Q3.2 Can a rule-based reasoning model be used to support land management planning at regional level?*

- *Q3.3 What are the main causes of land use conflicts as perceived by the local people?*

- *Q3.4 Can remote sensing indicators be used to map conflict areas in land use / management?*

1.6 The structure of the study

The research is composed of three main parts, showing a methodological development of a bottom-up planning from the *terroir* to the regional level (Fig 1.2). Each part is composed of chapters that are based on journal articles.

- Chapter 1 introduces approaches to land use planning according to changing international views and more specifically applied to the context of land degradation control and sustainable development in Burkina Faso. Following from the discussions of concepts, selected objectives are derived focussing on key problems and research questions related to bottom-up land use planning.

- Chapter 2 presents an approach for defining the management units relevant to all the stakeholders in a village community-based land management system, using planning information collected through PRA during the participatory planning process. Using PRA and household survey data collected in a case study in western Burkina Faso, the hypothesis was tested that the factors determining the definition of the land management units are based on the objectives, perceptions and constraints of the different groups of stakeholders. These factors were used for spatial analysis and mapping using GIS.

- Chapter 3 presents an approach for integrating local participatory land management in regional planning using GIS, and contributing to a bottom-up approach to land use planning. The proposed approach uses a geo-data abstraction procedure developed in spatial data handling theory. It is based on the use of the spatial distribution of specific information issued at one planning level, as a means of communication with the other. Considering that both levels should mutually support each other, a bi-directional procedure was used to operate the integration. It consisted of a bottom-up procedure for regional planning based on a spatial abstraction method and regional feedback to support the lower planning levels, using the regional information during the local planning process.

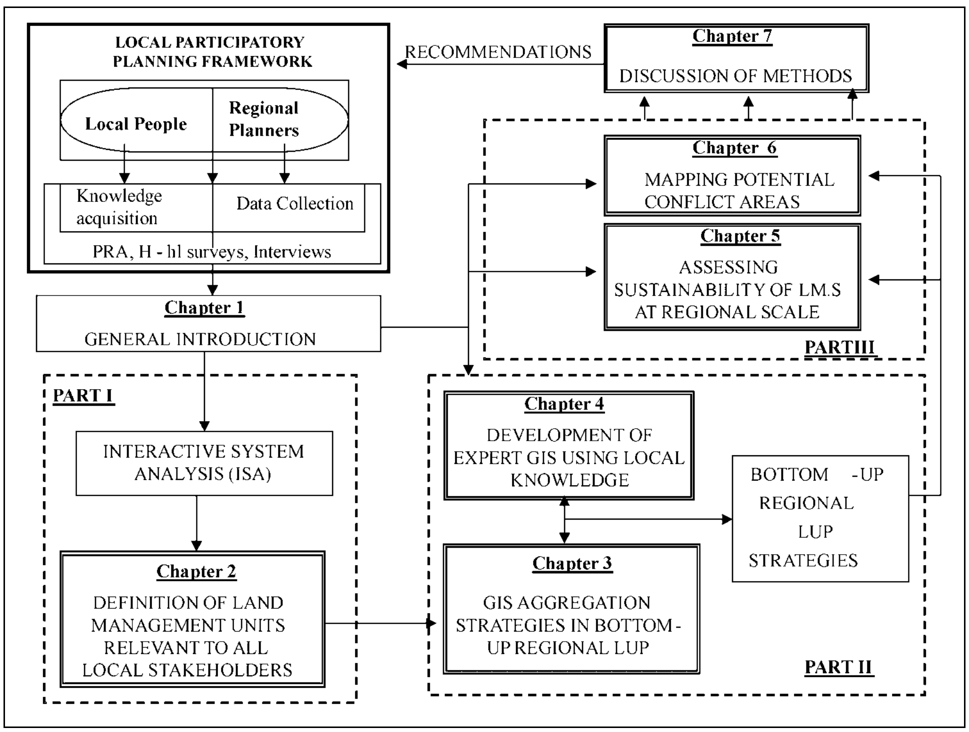


Figure 1.2 Flowchart of structure of the study

- Chapter 4 presents a GIS expert system capable of mapping land degradation areas at regional level using the knowledge of local people collected from PRA surveys in the study area. It combines the knowledge of local people about land degradation (used as expert) together with biophysical, socio-economical and cultural factors to derive predictive areas of potential land degradation at the regional level. The land degradation map derived from the expert system should be similar to that produced by experienced land managers after considering the ecological, economical and socio-cultural characteristics of an area.

- Chapter 5 presents a method to assess the sustainability of local land management systems at a regional scale, using a participatory approach. It also compares different methods of evaluating the sustainability of the local land management systems from a regional perspective. Specific attention was given to the analysis of the results of the expert GIS applied for evaluating the probable impact of different land management scenarios on the global status of land degradation at the regional scale.

- Chapter 6 presents an approach of conflict risk mapping as a method to study and predict the conflicts occurring in participatory bottom-up regional planning for sustainable resources management. The approaches to conflict management are mostly concerned with consensus building among the groups of stakeholders, developing workable projects or creating a tool to identify the economic interests and inherent conflicts of natural resources management. This study emphasizes the spatial dimension (which is omitted in most cases) as the key point for conflict analysis leading to conflict management.

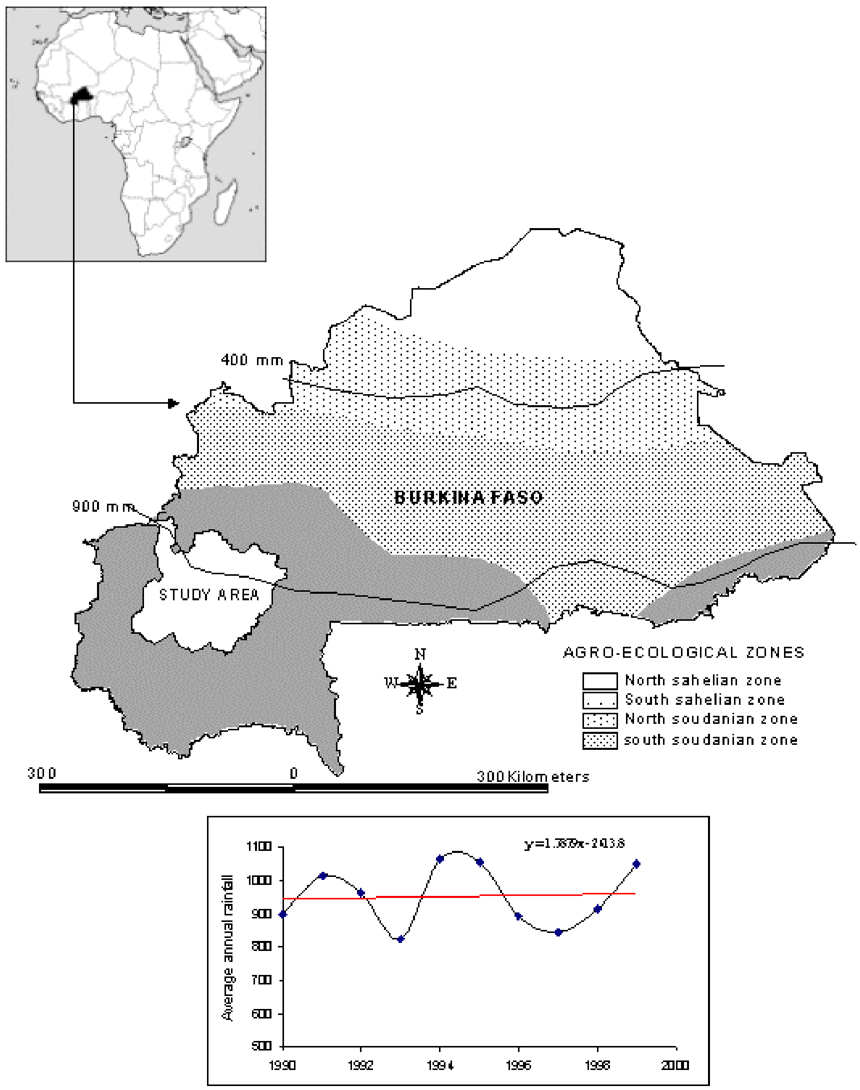
- Chapter 7 discusses the different steps followed during the study and highlights the main findings. It identifies potential contributions to local participatory land use planning and discusses the implications for regional policy, allowing the promotion of bottom-up regional planning. Finally, it draws conclusions and formulates some recommendations for future research in order to improve the use of geo-information as a participatory land use planning decision-making tool.

1.7 Description of the study area

Burkina Faso is a flat country with elevations ranging generally between 200 and 600m, characterized by highly heterogeneous soils of generally low agronomic value. The research area corresponds to the Province of Houet located in the south-western part of the country, between 5^0 - 3^0 west and $10^0 30$ -13^0 north. The administrative organization used until recently shows a hierarchical structure composed of 14 districts and 374 villages within the province. The population was estimated at 935,343 people in 1996 (INSD, 1998). Fifty percent of this population is concentrated in the district of Bobo-Dioulasso. The city of Bobo-Dioulasso, which is the second largest city and the economic capital of the country, is located in this district.

1.7.1 Physical characteristics

The province is in the south-Soudanian agro-ecological zone, where the annual rainfall ranges between 800 and 1200 mm. The climate is a transition type, between the Soudanian and the Guinean climates, with a six-month wet season alternating with a dry season. The analysis of the rainfall distribution shows high inter-seasonal, spatial and inter-annual variabilities. The rainy season lasts from May to October with rainfall peaks in August varying from 220 to 400 mm per month. The mean annual rainfall registered for the most north-eastern station (Hounde), the central (Bobo-Dioulasso) station and the most south-western station (Toussiana) in the province were 913 mm, 1040 mm and 1143 mm respectively, for the period between 1960 and 1989 (Ouedraogo, 1993).



Average annual rainfall pattern in the study area between 1990 and 1999

Figure 1.3. The study area

The distribution of the average annual rainfall based on the data collected in the five meteorological stations of the province between 1990 and 1999 shows regular fluctuations. The average temperature ranges between 25° and 29° C during the rainy season and between 35° and 40° in the dry season. The inter-annual variation in temperature is quite low (around 1.5 °) compared to the inter-seasonal one. Based on the monthly variations, four periods may be distinguished in the year:

- December – February, which is a relatively cool period with temperatures averaging around 20° with low peaks of less than 18°.
- March –June, with high temperatures above 35°.
- July – October, corresponding to the rainy season with again low temperatures averaging around 27°.
- October – November, corresponding to the end of the rainy season with again relatively high temperatures above 30°.

Despite relatively low altitudes, the relief in the province is one of the most varied in the country, with heights ranging from 250 to 500 m. Plains and plateaus are the main terrain units. They are separated by a strait fault line of nearly 150 m in height, which crosses the province from north-east to south-west. According to Boulet and Leprun (1969) and based on the French soil classification system (CPCS, 1969), three main soil types are found: (1) Lithosols developed around various rock outcrops such as sandstones, ironstone and granite, very shallow and not suitable for agriculture. (2) Tropical ferrugeneous soils, well developed on schists. (3) Ferrallitic soils, well developed on sandy clay.

The flora in the province is typical of the Soudano Guinean zone. It is mostly a savannah type, composed of woodlands, shrubs, grasslands and riparian forests along the rivers. The vegetation species found in the province are generally higher and more densely distributed than they are in the rest of the country. The main tree species occurring are: *Butyrospermum parkii, Parkia biglobosa, Burkea Africana, Detarium micro carpum, Isoberlina Doka, Anogeissus leiocarpus, Daniella oliveri* and *Borassus Aethioum* (Ouedraogo, 1993). Eleven natural reserves are located in the province covering 18% of the total area, which gives evidence of the province's relatively abundant natural vegetation compared to the northern provinces. However, the natural resources are seriously threatened by increasing human pressure.

1.7.2 Socio-economic characteristics

The province is traditionally the territory of two main ethnic groups. The *Bobo* occupy the northern and the central parts. The *Senoufo* (composed of the sub-groups *Toussian* and *Tiefo*) are more to the south. Other minor local groups are also found in the east (the *Vigue*), the west (the *Sambla*) and the centre (the *Dioula*). It is the meeting of this last group with the Bobo the formed the basis of the emergence of the city of Bobo-Dioulasso. In recent years, the traditional ethnic balance has broken down as the droughts of the 1970s - 1980s led to an increasing influx of *Mossi* from the densely populated central plateau. Other groups have also immigrated into the area. Among them are the pastoralist herders (*Fulani*) who have contributed to the large number of livestock. In 1991, the population of immigrants was estimated at nearly 40% of the overall population (source: regional planning service).

The overall population of the province has tripled in twenty years, evolving from 306,670 in 1975 to 585,722 in 1985, then to 935,345 in 1995 (source: national census). The province is characterized by a highly variable spatial distribution of the population per district, ranging from 1.9% to 50% concentration in the district of Bobo-Dioulasso. The increasing human and animal pressure (due to a high population growth rate and the important immigration) is rapidly altering the land use and natural resources regimes in the province. These factors are believed to be responsible for deforestation leading to environmental degradation.

Agriculture is the main activity in the study area. It is based on two types of cropping systems in which the fallow method is still more or less practised: The sorghum/maize system (mainly for auto-consumption), and the cash-crop cotton/maize system (maize is shifting to a cash crop). Rainfed fruit tree cultivation (mango, citrus), and horticulture are expanding. Livestock farming is the second largest activity, based mainly on extensive grazing. The relatively high potential of natural resources of the province compared to that of the northern province makes it a destination for an important seasonal cattle migration (transhumance). The development of cash crops, mainly cotton cultivation, has introduced new management practices such as the use of fertilizers and mechanization. A growing number of farmers are turning to an integrated farming system, combining agriculture and small-scale livestock farming. However, extensive agriculture is still widely practiced and this (because of the population pressure) generates a very high demand for agricultural lands. Within 15 years (1984 – 1999) the area under cultivation has increased by 75%, from 131,700 ha to 233,800 ha (source: national agricultural statistics).
Despite this situation, the province constitutes one of the most important development pools of the country. This is one of the reasons it was chosen as a pilot area for implementing the *Gestion des Terroirs* approach. In 1992, the government started a participatory land management project in the area, with the help of the national programme (PNGT). The pilot project aimed at decentralizing the management of the national reserve forest of Maro, to the level of the villages surrounding it, in order to ensure its sustainability. The forest of Maro is located in the north-western part of the province, in the neighbourhood of a natural lake sheltering a population of hippopotamus, which is classified as a biosphere reserve by UNESCO. The forest of Maro was established by the colonial administration in 1920 as a fuel wood reserve area for supplying the steam engines of the railroad. It was later brought under the control of the National Forestry Service, but the top-down forestry policy could not prevent the agricultural encroachment and over-exploitation of the resources. The population of the surrounding villages exploits the resources not only for household needs but also as a source of income, by selling firewood in the city of Bobo-Dioulasso. The local population also uses the lake for fishing and irrigating market gardening plots. In 1992, a participatory integrated land use planning process was initiated in that area by the PNGT, with the following components:

- Participatory management of the Maro forest by an inter-village committee representing 17 villages surrounding the forest. It has the objectives of raising income for the local people, supplying fuel wood to the province capital, and conserving the forest and the biosphere;

- A land use plan including the creation of a stable pastoral zone to provide security for the pastoralists living in the area and to avoid the increasing pressure of cattle on the reserve areas and the reallocation of cultivation areas for the farmers;

- Implementation of intensification activities such as water and erosion control and organic fertilizing;

- The protection of riverbanks against soil erosion and sedimentation;

- The definition of local conservation areas to protect the village cultural sites.

Based on the positive results of the pilot land use planning project, a vast programme is being implemented, currently at the scale of the province but with aims to extend participatory village land use planning nation-wide.

CHAPTER II*

DEFINITION OF LAND MANAGEMENT UNITS IN PARTICIPATORY LAND USE PLANNING USING PRA AND GIS

* This Chapter is based on Sedogo, L.G. and Groten, S.M.E. (2000) Definition of land management units for GIS support to participatory planning: A case study on participatory land management in Burkina Faso. Canadian Journal of Development Studies **XXI:** 523-542. Special Issue in Participatory Development, University of Ottawa.

Abstract

The *"Gestion des Terroirs"* approach implemented in Burkina Faso recognizes a diversity of interests in the village territory in relation to natural resources among different social groups, such as (native and immigrant) farmers and pastoralists, women and men, youngsters and elders. Despite the richness of participatory rural appraisal (PRA) information used in the planning process, efficient geographic information gathering and relevant spatial analytical tools necessary to support negotiation among the stakeholders are lacking. Despite the recent development in participatory GIS, methods are needed to construct more knowledge-based GIS capable of dealing with the indigenous knowledge systems prevailing within the local communities. In this study we propose an approach linking PRA and GIS by using information collected through participatory methods as GIS input for spatial analysis. It is based on a case study of participatory land use planning in the village of Kadomba, located in southwestern Burkina Faso. To this purpose, we identified and discussed the main factors defining the land units where specific land management activities should be undertaken within the framework of the village land use plan, according to the views and perceptions of the different stakeholder groups. The steps taken were as follows. (1) PRA tools were used to extract the perceptions of the different groups on resources and management constraints. (2) Interview data from 143 villagers randomly selected were statistically analysed to infer the socio-cultural and economic constraints. (3) A land cover map of the village territory was used to identify the potential land management units. (4) A digital elevation model and a slope map classified according to criteria inferred from the farmers' knowledge were overlaid with the land cover map for spatial analysis. The study showed that, despite their importance, the socio-cultural and economic factors do not play a significant role in defining and mapping by means of a GIS the local land management units relevant for the stakeholders. The farmers' knowledge relative to biophysical constraints such as flood and erosion risks constitutes relevant factors that can be used as GIS inputs to define and map different local land management units. The factors driven by the local participatory planning regulations were also relevant for defining and mapping the local land management units in a GIS.

2.1 Introduction

Geographic information systems (GIS) have been widely used to support land use planning processes by providing baseline data and producing output information for decision-making. With the introduction of participatory approaches in development programmes, the issues of building and implementing strategies based on the objectives, perceptions and knowledge of local people have become essential for land use planners. To match the needs of planning at the decentralized level of the local community, as recommended by UNCED (1992) and FAO (1995), new methods based on recognition of the importance of local knowledge and perceptions are needed (Scoones and Thompson, 1994; Campbell, 1992). More importantly, land use planning has shifted from an output orientation (a land use plan) towards a process orientation, in which different criteria and views of stakeholders are evaluated as a basis for more or less democratic decision-making (FAO, 1993; Groten, 1998). This means that conceptual approaches to building GIS for supporting participatory land use planning processes should henceforth be able to cope with concepts, methods and tools used in this new planning environment. For instance, new methods of data collection and processing should be able to integrate information in soft formats inherent to the indigenous systems, together with the traditional set of hard and quantitative data for decision-making.

The principle of participation has many aspects (Oakley et al., 1991; Vainio-Mattila, 2000). Based on this concept, many applications have been developed in various fields, including research, education, healthcare resources management, etc., all other the world (Freire, 1972; Chambers, 1983; Chambers et al., 1989; Scoones and Thompson, 1994; Adriance, 1995; Dirorimwe, 1998; Hadi, 2000; Gasteyer, 2000). However, participation seen as “empowerment” is considered as the steering line of the participatory models for sustainable development (Oakley et al., 1991, UNCED, 1992; FAO, 1995; Vainio-Mattila, 2000; Cowie, 2000). The *Gestion des Terroirs* approach introduced in several West African countries during the last decade stems from this principle (UNSO, 1994; Capo-Chichi et al., 1995). The literature abounds in examples of similar decentralized community-based approaches in other parts of Africa (Murombedzi, 1991; Murphree, 1993; Nuttens and Said, 1995), in South Asia (Poffenberger and McGean, 1992) and Australia (Campbell, 1992).

Gestion des Terroirs is a participatory land use planning and land management approach aiming to improve both the use and management of natural resources, and the living conditions of the rural population within the intervention level of the village and its lands. It recognizes that villagers know more about the local environment than outsiders do, and that there are diverse interests in relation to natural resources among different social groups, such as farmers and pastoralists, women and men, youngsters and elders. The *terroir* is a social construct (Teyssier, 1995; Roling and Wagemaker, 1998) as well as a decentralized geographic planning unit, where different groups of stakeholders (local and outsiders) should agree upon mechanisms to plan, invest and implement land use and land management activities. Therefore, a local land use plan is the result of a participatory process involving negotiations among the local groups and, through the village land management committee, between the local community and external partners. The approach contributes to improving local land use planning and natural resource management (van den Briel et al., 1994; UNSO, 1994; Capo-Chichi et al., 1995), leading to a better adoption of land management activities such as water and conservation measures, forestry and rangeland management, agricultural intensification, etc., by the local communities. Yet, evident constraints on its successful implementation do still exist. For example, the implications for some groups (i.e. pastoralists, women) are recognized only to a very limited extent. The approach does not fully utilize the potential of local people's knowledge in the planning and management process. Because of a lack of in-depth analytical capabilities, the local decision-making boards often fail to propose new alternatives for land use or management practices. Moreover, the approach stays very local and hardly deals with the higher levels at which natural resource use also takes place (e.g. bigger watersheds, districts).

In this process, participatory rural appraisal (PRA) is the toolbox used for local capacity building and for supporting the different phases of the participatory planning process. Indeed, different PRA tools are implemented by the local people to provide information relating to the biophysical, socio-cultural and economic aspects of their *terroir*, which is used as input for the different phases of the participatory planning process. Many authors have emphasized the advantages of using PRA for local knowledge elicitation – its reliability and relevance as compared with more traditional methods, and therefore its importance in participatory planning (Maschaneras et al., 1991; Pretti and Guijt, 1992; Paliniswamy et al., 1992; Cornwall et al., 1993; Chambers 1994a; Maxwell and Bart, 1995; Capo-Chichi et al., 1995).

For rural research approaches however, it is recommended that PRA should be combined with other methods (i.e. statistical analysis) so as to enhance its contribution to the body of research findings on rural matters (Loader and Amartya, 1999). Despite the richness of the information extracted using PRA methods, efficient geographic data collection and spatial analytical tools necessary to support negotiations and land use decision-making are also lacking. Efforts have recently been made to introduce aerial photography as a participatory planning tool (Groten, 1997) and to promote participatory GIS (Gonzalez, 2000; Rambaldi et al., 2000; Al Kodmany, 2001; Nyerges et al., 2002). Although most approaches propose GIS development and implementation by the local communities, this is difficult to implement owing to cost-effectiveness problems and organizational and technologic gaps within rural communities (Henneman et al., 1998). Besides, conceptual and technical obstacles still need to be overcome in order to construct more knowledge-based GIS capable of dealing with the indigenous knowledge system, which is the *terroir.* Herein lies the challenge of proving the technical relevance of GIS for addressing local land use problems, based on information collected through PRA. There is also a need to provide the local planners with relevant outputs – reflecting the views, objectives and perceptions as expressed by the various stakeholder groups – to fairly and reliably support the negotiations and decision-making processes.

It is the aim of this study to contribute to linking PRA and GIS by using information collected through participatory surveys as GIS input for spatial analysis in local land use planning. For this, the main factors determining the definition of the land management units relevant to all the stakeholders are identified and discussed, based on a case study of a *Gestion des Terroirs* approach in a village in southwestern Burkina Faso. Furthermore, we examine the relevance of these factors for mapping management units with a GIS. Defining the management units will consist of the following steps:

- Identifying both the internal (socio-cultural, economic and biophysical) and external factors that contribute to determining the land management units in the village, using PRA and household survey data;
- Describing and mapping the land use zones as defined according to these factors;
- Identifying and mapping in GIS the units where specific management activities may be undertaken to achieve the planning goals and objectives.

2.2 Methods

2.2.1 Presentation of the study area

The study area is the village of Kadomba, located in southwestern Burkina Faso, near the city of Bobo-Dioulasso in the province of Houet (see Figure 2.1).

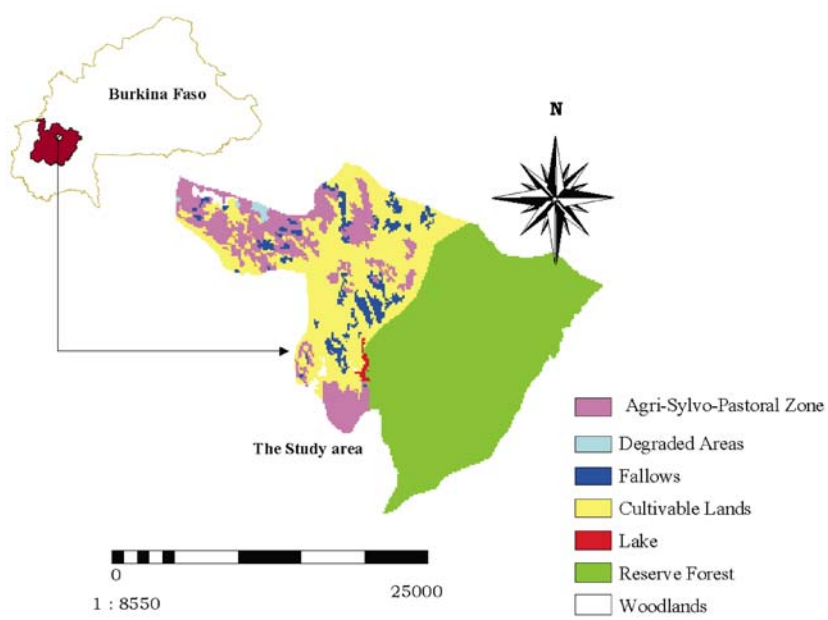


Figure 2.1 The study area: Land use map of Kadomba village territory and forest reserve

The climate is characterized by a six-month wet season, suitable for agriculture, alternating with a dry season. The annual rainfall ranges between 900 mm and 1200 mm. The vegetation is a savannah type, composed mainly of woodlands, shrubs, floodplain grasslands and riparian forests. Shallow to medium soils (<40 cm), gravely and/or sandy to clayish with low chemical fertility and a high susceptibility to erosion, are found in the savannah. Deep soils (>100 cm), alluvial/clayish with a high chemical fertility, are also found in areas adjacent to water sources, which have high flood risks.

Kadomba is one of the villages bordering the national protected forest of Maro. Agriculture is the main activity and is based on two types of cropping system in which fallow is still more or less practised: the sorghum/maize system (mainly for auto-consumption) and the cash crop cotton/maize system (maize shifting to a cash crop). Rainfed fruit tree cultivation (mango, citrus) and horticulture are expanding. The development of cash crops, mainly cotton cultivation, has introduced new management practices such as the use of fertilizers and mechanization. Population pressure and low investment capacities generate a very high demand for agricultural lands. Livestock farming is the second activity in the area, based mainly on extensive grazing. The ethnic group of *Bobo* is the dominant native population. However, the severe droughts of the seventies and eighties and the eradication of the tse-tse fly favoured a massive immigration of other groups of agriculturalists (the *Mossi*) and herdsmen (the *Fulani*) from the central plateau and the northern part of the country. Despite a relatively high potential of natural resources, population pressure is increasingly contributing to environmental degradation. In 1992, the government started a participatory land management project in the area, based on the *Gestion des Terroirs* approach and conducted under a national programme (PNGT). This project had several multiple objectives:

- Participatory management of the Maro forest by an inter-village committee, representing 17 villages around the forest, with the multiple objectives of raising income for the local people, supplying fuelwood to the provincial capital, and conserving the forest and the biosphere;
- A land use plan, including the delineation of a local pastoral zone to safeguard the pastoralists living in the area and avoid the increasing pressure of cattle on the reserve areas, and the reallocation of cultivation areas for the farmers;
- Implementation of intensification activities, such as water and erosion control and organic fertilizing;
- The protection of riverbanks against soil erosion and sedimentation;
- The definition of local conservation areas in order to protect the village cultural sites.

2.2.2 Survey methods and data collection

Data of the study area were collected using PRA and household surveys. Secondary PRA data were compiled from a previous participatory diagnosis carried out in 1993 with the aim of preparing a participatory land use plan. Primary PRA data in the form of sketch maps, historical profiles, diagrams and group interviews were also collected during a PRA survey carried out in June 1999 to update the information. A transect was implemented to record local technical knowledge about the resources. Scoring techniques were used to

rank the interest of each local stakeholder group in the different types of resources. A hand GPS was used for georeferencing individual and collective management units (e.g. fields, cattle paths, parks, pastoral camps, etc.).
A land cover map was digitised from an interpretation of scale 1:20,000 aerial photos of the study area. Contour lines were digitised from a 1:200,000 topographic map from which a digital elevation model (DEM) and a slope map were derived. In the household survey, 143 farmers randomly selected from all groups were interviewed using the following stratification criteria: age, gender, social origin and socio-professional activity. A stakeholder analysis was carried out to identify the groups of land users (local and regional) and their interests in the local land use planning and the land management process.

2.2.3 Identification of driving factors defining the local land management units
The procedure for the definition of land management units is shown in the flow diagram in Figure 2.2.

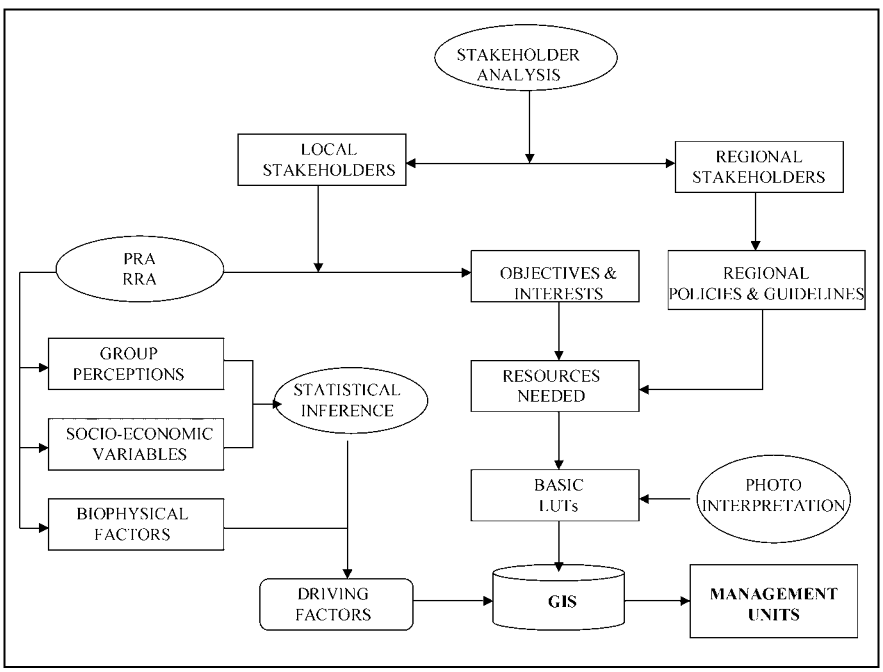


Figure 2.2: Flowchart of the procedure for defining the land management units

Table 2.1 presents the different factors (composed of production and ecological conservation functions, and socio-political/economic policies and facilities) that may have spatial impacts on the planning and management practices. They pertain to the different dimensions (socio-cultural, economic and biophysical) and were clearly identified from the PRA data. However, such information is aggregated at group level and not free from bias. To assess their relevance, socio-cultural and economic variables measured during the household survey were statistically compared with the group information collected from key-informant interviews and PRA, and used as a hypothesis to be tested. The social classes involved were the following: Age-Class (youngsters, elders), Gender (men, women), Origin (natives, migrants), Socio-professional activity (agriculturalists, pastoralists).

Table 2.1 Driving factors hypothesized to influence the management units at local level

Driving factors		Rationale	Indicators
Internal factors	**1. Cultural:** The tenure system and rules of access to land	1.1 Women have less access and rights than men 1.2 Youngsters have less access and rights than elders 1.3. Migrants are well accepted but have less access and rights than natives 1.4. Pastoralists have less access and land rights than agriculturalists	-Customary access rights to resources as perceived by the different groups of stakeholders Constraints on the main resources: cultivable land, pastures (availability, quality) -Limitation on tree planting, and erosion control
	2. Economic: Production factors	2.1 Correlation between production factors reflects high pressure on land and resources to achieve production goals	Labour availability Field size Number of animals
	3. Biophysical: Factors influencing local management strategies	3.1 Minimizing flood risk determines the farmers' interests in land units 3.2 Pastoral units are residuals of agricultural units	Land utilization types Topography/terrain units
External factors	**4. Policy driven:** Laws and national land use planning regulation	4.1 The land reform law sets spatial conditions to be respected by all stakeholders	Land utilization types Spatial conditions
	5. Production driven: Supporting activities	5.1 Erosion and water control activities are implemented with outsiders in priority areas	Land utilization types Topography/landscape
	6. Planning driven: Commonly agreed activities from the participatory planning process	6.1 A permanent communal pastoral zone helps to stabilize and safeguard the pastoral activity 6.2 Rules for the sustainable management of the reserve forest	Land utilization types Participatory planning rules

Descriptive statistics using the relative frequency of farmers' responses allowed the perceptions of the different groups to be compared. The non-parametric Mann-Whitney *U*-test was used to test the significance of the differences in perception between the groups. The null hypothesis was that there is no significant difference between the perceptions of these groups. The socio-cultural variables included: (1) access to resources, assessing the impact of the customary land rights on each group; (2) constraints on agricultural land (land availability, soil quality); (3) constraints on pastoral lands (pasture availability, degradation of rangelands).

The economic factors were also statistically analysed to determine their impact on land management units. These factors relate mainly to the basic managerial functions of the farming system (land, labour and capital), which can be used to characterize most African rural situations (Upton, 1987, p5). The extensive production systems in the study area require high inputs of land and labour for the households to satisfy their main objectives of food security and raising income. For the agriculturalists, animal (particularly cattle) ownership is a general indicator of the economic wealth of a household. As defined in Table 2.1, the main economic indicators are the number of animals, field size and labour availability. The pastoral system is also characterized by the high number of animals; hence large grazing areas are necessary. Thus, finding a correlation between these variables may show the saturation of the land and the over-use of the resources. Even though a correlation does not demonstrate causality, it can be used to falsify a hypothesis if the correlation predicted by the hypothesis is not observed (Currie, 1991).

In addition, external factors that had spatial impacts on the planning and local land management activities were identified. These are mainly related to the intervention of outsiders (national and regional).

2.2.4 Mapping the management units

To map the management units, we used the farmers' perceptions based on slope and height, as follows: (1) Water and erosion control should be given priority on the steeper slopes in agricultural areas. Slopes between 0 and 31% were classified in three categories (low: <3%, moderate: between 3 and 10%, and high: >10%). (2) Flood risk can be minimized by avoiding the use of lowlands; hills and sloppy areas are not suitable for agriculture and are left for pastures. During the transect, the altitude of the flooded areas in the normal rainy season was estimated from farmers' knowledge to be about 310 m (altitude ranges between 280 and 400 m in the area). The agricultural areas were classified in three categories of elevation, using the DEM derived from the topographic map (low: <320 m, moderate: from 320 to 360 m, high: >360 m). Based on the criteria of farmers' preferences for terrain units, the cultivable areas falling in the second height category were selected as a GIS layer. A regression was run to find the correlation between the location of the cultivated areas and the altitude, and the equation was used to predict potential extension zones of agriculture that reflect the biophysical criteria set by the local farmers. In addition, external factors that contribute to defining local land management units were identified and used as GIS mapping criteria.

2.3 Results

2.3.1 Internal factors determining the definition of the management units

(1) Socio-cultural factors

According to the group interviews, the property rights to the land are stronger at the levels of clan and lineage than at individual and household levels. Inheritance is the most common way of access to land among the native population. Restricting immigrants' access to land to borrowing and by limitations on land management practices is imposed to maintain a permanent link between the land and the original owners. The results of the analysis of the socio-cultural factors are summarized in Table 2.2 by the relative frequency of farmer responses.

Table 2.2 Perceptions of the different stakeholder groups regarding access to resources and the main constraints (based on the relative frequency of response)

Main groups	Access to resources			Constraints on agricultural lands				Constraints on rangelands			
	Difficult	Easy	Total	No	scarcity	Soil quality	Total	No	scarcity	quality	Total
Natives (N = 88)	17	83	100	7	60	33	100	38	27	35	100
Immigrants (N = 31)	52	48	100	16	55	29	100	39	22	39	100
Pastoralists (n = 24)	35	65	100	8	92	0	100	0	96	4	100
youngsters (N = 41	25	75	100	3	72	25	100	22	47	31	100
N.elders (N = 47)	28	72	100	15	57	28	100	39	30	31	100
Men (N = 59)	30	70	100	9	67	24	100	31	37	32	100
N.women (N = 29)	19	81	100	8	57	35	100	32	41	27	100

These results show that the different groups consider access to resources relatively easy. However, it seems difficult for the majority of the immigrants to gain easy access or secure land rights. These results also show that the major constraint on agricultural lands, expressed by the majority of people in all the stakeholder groups, is the scarcity of the resource. Within the native population, the younger people feel the problem of land scarcity more (72% of the relative frequency of response). The pastoralists clearly perceive a scarcity of both cultivable lands and rangelands (respectively 92% and 96%). Furthermore, the result of the Mann-Whitney *U*-test in Table 2.3 attests that the perceptions of access to resources do not differ significantly between the groups within the native population and the pastoralists. However, there is a significant difference in perception between the immigrants and the natives.

Table 2.3. Mann-Whitney *U*-test assessing the difference in perception among the stakeholder groups

	p-value				
	Youth/ elders	**Men/ Women**	**Native/ immigrants**	**Natives/ pastoralists**	**Immigrants/ pastoralists**
Access to the natural resources	0.689	0.117	000	0.0613	0.223
Size of fields (cereals and cotton)	0.443	-	0.621	000	000

(2) Economic factors

Agriculture is the major activity for most of the people in the study area, and an indicator of the strength of the agricultural domain is the size of the household exploitation (composed of cereal and cash crop fields). The result of the Mann-Whitney *U*-test in Table 2.3 shows that there is no significant difference among the agriculturalists (natives and immigrants), in terms of size of exploitation. However, there is a significant difference between the agriculturalists (natives and immigrants) and the pastoralists. Furthermore, the results of Spearman's correlation in Table 2.4 show that for the agriculturalists (natives and immigrants), labour availability (the number of active persons in the household) is significantly correlated with the size of the exploitation (*rs* = 0.674 for cotton and 0.676 for cereal).

Table 2.4. Spearman's correlation's rho (*rs*) between social and economic variables for the agriculturalists. (Ccorrelation is significant at 0.05 level (Sig. 2-tailed)

		Number of activities /household	Size of cotton field	Size of cereal fields	Number of cattle	Accessibility to resources
Number of activities per	rs	1.000	0.674	0.676	0.688	0.024
household (agriculturalists)	Sig.	.	**0.000**	0.**000**	0.**000**	0.795
Size of cotton field	rs		1.000	0.697	0.697	-0.17
(agriculturalists)	Sig.		.	0.**000**	0.**000**	0.855
Size of cereal fields	rs			1.000	.600	0.047
(agriculturalists)	Sig.			.	.**000**	0.616
Number of cattle	rs				1.000	-0.114
(agriculturalists)	Sig.				.	0.219
Accessibility to resources	rs					1.000
	Sig.					.

Table 2.4 also shows that the number of cattle correlates significantly with the size of exploitation for the agriculturalists *(rs* = 0.600 for cereals and 0.697 for cotton). Despite the significant correlation between the size of cotton and cereal fields (*rs* = 0.697), cotton is cultivated on a larger scale than cereals. From the survey it can noted that the mean size of cotton fields is around 3.9 ha, whereas cereal fields (maize and sorghum) have a mean size of 3.3 ha. Within the group of native people, the youth tend to have larger cotton fields than the elders. The mean sizes of exploitations for the natives and immigrants are nearly identical at ~ 7.5 ha, and for the pastoralists nearly 1 ha. Within households, the small ruminants (sheep and goats) belong to the individual members; the women have significantly more animals (2.7 on average) than men (1.6 on average), whereas the numbers are nearly the same for elders and youth. The mean herd size of cattle kept by the pastoralists is about 90, whereas for the agriculturalists it is nearly 5.

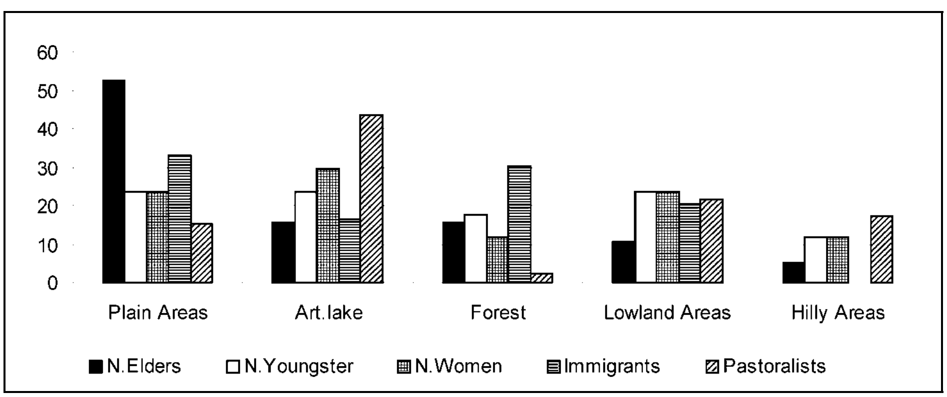


Figure 2.3. Perceptions of the interest of the stakeholders' groups for different natural resources and terrain units

(3) Biophysical factors

The results of the PRA survey showed that the interests of the local people in land use (management) differ according to the type of terrain unit. The classification matrix giving the preferences of the groups is shown in Figure 2.3. The figure indicates that most agriculturalists prefer the lands located in plains with low to moderate slopes. On the other hand, the pastoralists prefer the water reservoir, followed by the lowlands, where they say they have the best forage (quality and availability). The location of their camps and parks on hilly areas (to minimize the risks of conflicts with agricultural lands) explains the relative importance given to these types of terrain units.

2.3.2 External factors

The external factors contributing to the definition of the management units relate mainly to the impact of the support given by outsiders (state, regional services, NGOs) to the local population in order to achieve sustainable development objectives. These factors were revealed by the links between the local community and outside partners, which were shown by the PRA tools (venn diagrams) and confirmed by interviews with the extension agents.

(1) Policy-driven factors

The national reform law (RAF, 1998) codified some land use planning guidelines to support the participatory planning process and safeguard the different land user groups. This has resulted in top-down policies that have spatial impacts at the different levels (from local to national), concerning mainly:

- The delineation of national forest and wild life conservation areas in a UTM coordinates system where agro-pastoral production activities are excluded.

- The definition of buffer zones around the delineated pastoral units in order to prevent the encroachment of other activities (agriculture mainly). These buffer zones are respectively 100 m for cattle paths, and 500 m around the reserve areas, the delineated pastoral zones and watering points located outside the pastoral zones.

- Outside partners use the rate of implementing these policies as an indicator to measure the degree of village involvement in the participatory planning process.

(2) Participatory project intervention factors

These factors are determined by certain activities implemented by the regional extension services, the participatory land use planning agency (PNGT) and the cotton growing company (SOFITEX) in order to support the local productive sectors (agriculture, livestock farming, firewood exploitation). In general, they are the result of negotiation and common agreement between the (local and regional) stakeholders during the participatory planning process. Implemented with the aid of the local population (money and labour) through the professional organizations and the planning committee, they concern mainly:

- *Agricultural activities:* With the help of the regional agricultural service, stony dikes are built along the contour lines to improve water and erosion control. The aim is to: (1) reduce runoff in order to prevent erosion and improve water infiltration, and (2) improve the effect of applying organic fertilizer.

- *Pastoral activities:* These relate to the construction of water reservoirs (where possible) or boreholes for improving cattle watering capacity during the dry season, and the delineation of pastoral zones to safeguard the livestock production activity. In Kadomba, negotiation between stakeholders resulted in the construction of a new dam by the PNGT in 1998 and the decision to define a pastoral zone in the form of a 1000m-long strip of land along the western border of the cultural domain, excluding the reserve forest. This process also involves the neighbouring villages in the bid to get a common pastoral area.

- *Forestry and other environmental activities:* these result from activities aiming to better protect, conserve and upgrade forestry resources. The following activities are being implemented in Kadomba. (1) Rotation plots: To promote sustainable use, the planted part of the national reserve forest has been divided into several plots, which are exploited in rotation to allow the natural regeneration of the trees. Security belts and firebreaks are created around these plots. (2) Buffer zones of 100 to 500 m are created for reafforestation along the rivers and streams (agriculture is excluded) in order to protect the banks. (3) Tree plantation in the bare lands helps to reclaim these degraded areas.

2.3.3 Spatial analysis

(1) Agricultural units

Agriculture is practised by all the groups and is mainly the source of food security and the symbol of self-sufficiency and social welfare. The principal resources involved are the cultivated lands composed of individual household fields. According to the results of the spatial analysis, nearly 75% of the area under cultivation lies on the low slopes ranging from 0 to 3%. Figure 2.4 shows other results of the spatial analysis, and the potential management units that can be mapped using the biophysical factors related to farmers' knowledge based on topography.

Figure 2.4a shows a classification of flood risk areas in the cultivable lands. Figure 2.4b indicates the priority areas for erosion control in the cultivable lands. Furthermore, the farmers' strategy to minimize flood risk was checked with a spatial correlation between the agricultural areas and the terrain units at an altitude ranging between 320 m and 360 m. As shown in Figure 2.4c, it indicates a strong correlation $R^2 = .92$. The regression equation ($Y = -0.3892X + 144$) was used to map the predicted agricultural extension zone towards higher altitudes, according to the biophysical factors set by the farmers. Figure 2.4d shows these predicted agricultural land use changes.

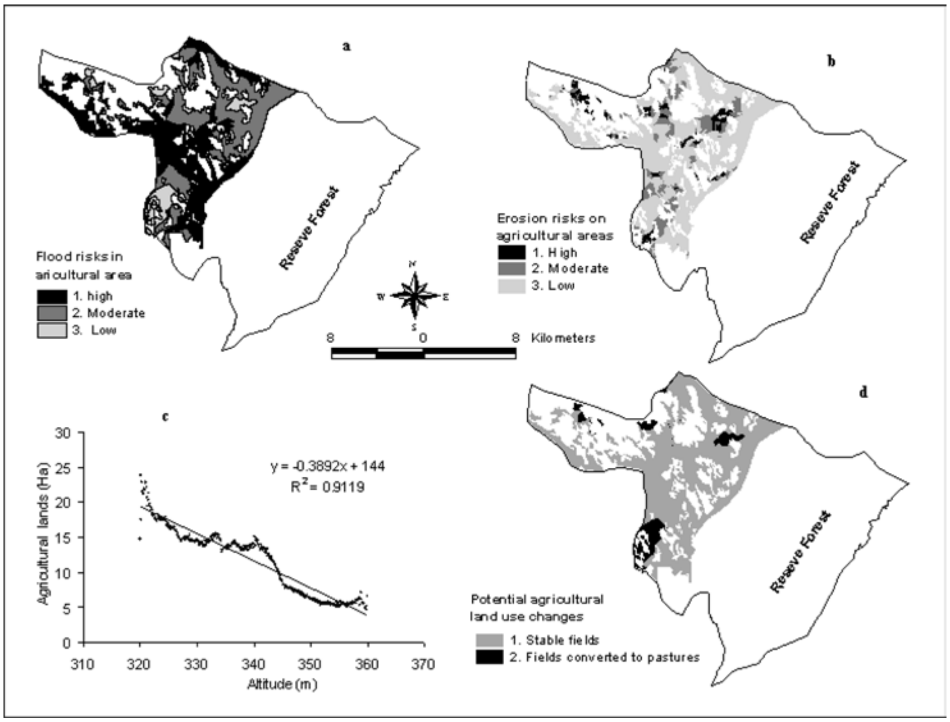


Figure 2.4 Mapping the agricultural management units, using the driving factors as spatial modelling inputs. Figure 2.4.a shows the importance of flood risk in the actual cultivable lands. Figure 2.4.b shows the erosion risk areas, which can be used as basis to define the priority areas for erosion control activities.

(2) Livestock farming units

In their diagram of production systems drawn during the PRA survey, the local farmers in Kadomba clearly mentioned the interactions of cattle with the other components of their land management system (cultivable lands, artificial lake households). However, grazing lands as management units were omitted, which confirms that grazing land as a geographic entity is an informal traditional land management unit. In practice, they are residuals of agricultural land and therefore can be mapped where formal agricultural or other socio-economic activities are not implemented. Figure 2.5b shows the results of the spatial correlation between potential grazing lands and the different terrain units. It indicates that an important portion (nearly 43%) coincides with the categories of lands that are also preferred by the agriculturalist. Figure 2.5a shows these lands that are likely to be converted into agriculture. From a temporal perspective, the livestock-farming units include fields after harvest (based on agreement with the owners), and recent and old fallows. It is then very difficult to make a clear spatial definition based on only the internal factors. Through the participatory planning process, however, the commonly supported agreement between stakeholders allows a stable management unit to be defined for the pastoralists in Kadomba and the surrounding villages.

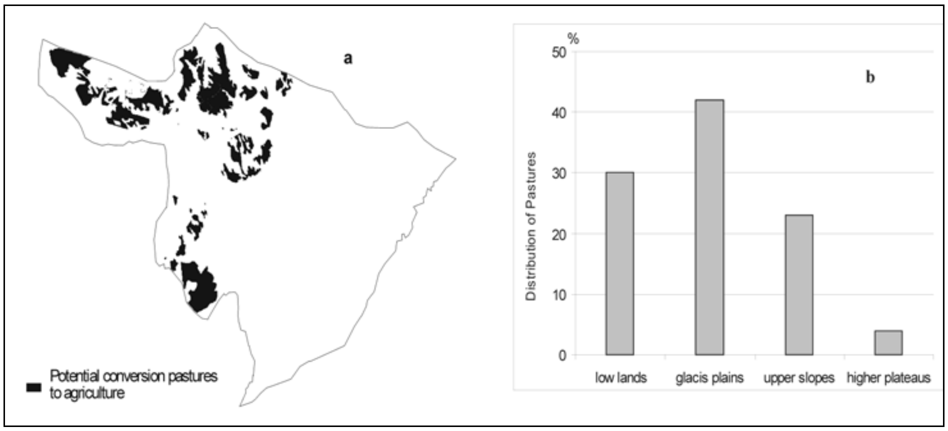


Figure 2.5. Result of the spatial analysis for grazing lands: Figure 2.5a shows pastures that can be converted into agricultural lands. Figure 2.5b shows the actual distribution of grazing lands over the landscape.

(3) Forestry and environmental units

Forestry units are mostly defined by a top-down policy (reserve areas imposed by the state). The colonial administration defined the reserve forest of Maro as a pool for fuel wood harvesting to supply the railway steam engines. Today, participatory forestry management is an important activity in the study area, allowing the reserve area to be protected while providing incomes during the dry season to the natives and migrant farmers (men and women), who sell firewood to the city of Bobo-Dioulasso. Apart from this, local wood lots and protection areas (mostly cultural sites) are also created by the local people. In Kadomba, protection of the riverbanks is also an important activity in participatory land management. Figure 2.6 shows a possible re-composition of land use in the study area, based on the different management driving factors.

2.4 Discussion

2.4.1 Relevance of the socio-cultural and economic factors

(1) Impact of the socio-cultural factors on the definition of the management units

The study shows that the socio-cultural factors play an important role in resources management in the area. Many studies on natural resources management in Africa, and especially in Burkina Faso, also show that local customary tenure remains the most important system through which people manage and gain access to land and other resources (IIED, 1998; Pare, 2001). The high percentage of native people perceiving easy access to the resources (83%) shows that these local customary rules and land rights are still favourable to the majority, including women. The relatively high proportion of pastoralists expressing easy access to the resources (65%) can be explained by the fact that they keep most of the cattle owned by the native farmers, who invest the revenues from cotton cultivation in livestock. That the majority of immigrants perceive difficulty as regards access and land rights (52%) may be an expression of a growing reticence of the native people *vis-à-vis* the important phenomenon of immigration in the area. As shown by the study, these factors strongly influence the rules of sharing the space and natural resources between individuals and groups, and constitute the basis of negotiations between them. They can also be used in conflict analysis and in setting the mechanisms of conflict management. The socio-cultural factors play an important role during the participatory planning process by delivering crucial information for physical planning. For instance, delineating and georeferencing the boundaries of the *terroir* is an important step in the process of the local community taking real control over its the resources (Eger et al., 1997; Schorlemer, 1997; Groten, 1997). Other important components of the local land management system, such as cultural sites to be transformed into local protected areas, and common resource management and exploitation areas (i.e. common wood lots or grazing lands), can also be identified and realized based on knowledge of the local customary systems.

(2) Impact of economic factors

Furthermore, the study shows that, despite their importance for the planning process, the economic factors do not intervene directly in the definition and mapping of the management units. Yet, understanding their impact is necessary to support decision-making during the planning and implementation of land management activities. For instance, the correlation between number of activities per household and field size can be used to understand agricultural land use changes in relation to population changes. It can also indicate the feasibility of agricultural management activities, such as intensification through manure fertilizing and erosion control, which are labour-intensive. Similarly, the correlation between field size and livestock population can be used to predict the sustainability of rangelands in relation to future population changes. Indeed, the fact that pastoral lands are residuals of agricultural lands means that their size will decrease, whereas under population pressure the size of agricultural land will increase, and *de facto* the number of cattle will also increase.

From the above development, we can conclude that among the agriculturalists the socio-cultural and economic factors do not have a spatial impact that allows a distinction to be made between different major groups (natives *vs* immigrants) and subgroups (men *vs* women, elders *vs* youngsters). Although these factors are relevant for the decision-making and planning processes, their spatial impacts do not significantly influence the definition of management units typical for any group or subgroup. Thus they are not feasible mapping indicators for the management units. However, the agriculturalists and pastoralists should be considered separately as homogeneous groups influencing (each in its own way) the definition of the management units.

2.4.2 GIS definition and mapping of the management units

Table 2.5 summarizes the different elements that can be used to define and map the management units, using a GIS, as shown in Figure 2.6 below. The study shows that the biophysical factors internally perceived by the local people and the external factors contribute more directly to defining and mapping the management units using a GIS. The agricultural units (fields) can be mapped using conventional data acquisition techniques (for instance, interpretation of aerial photographs). The study shows that the local perceptions collected using PRA tools are relevant for mapping information, as shown by the result of the spatial correlation. Furthermore, this information can be used as the basis for a spatial analysis, leading to the identification of different units (potential erosion control areas, potential field extension areas). Therefore, the local perceptions serve as a strong basis for defining relevant criteria that can be used to improve the local participatory land planning process.

Table 2. 5 Elements of defining, planning and mapping the management units

LUT	Management units	Relevant planning driving factors	Mapping driving factors	Mapping indicators
a) Cultivated lands	Fields	Cultural: Access, constraints (availability, quality) Economic: Field size, labour availability, number of cattle	Biophysical: Land utilization types (AP), topography, land units, soil/vegetation	Geometric lines (field boundaries) Pattern and tone of cultivated areas
	Erosion control site	Erosion control	Slope, height	Slope contour lines
b) Livestock farming units	Grazing areas / Pastoral reserve Vaccination park Cattle paths Watering point	Cultural: Access, constraints Economic: Number of cattle	Policy driven: Land utilization types, P.LUP plans, activity map Biophysical: Topography, vegetation (AP)	Biomass (criteria from participatory planning), vegetation, hydrology, roads
c) Forestry units	Natural reserves Planted areas, local forests Forest paths, firebreaks, exploitation site, rotation plots	Policy driven: National laws, regional policy land utilization types, participatory planning decisions	Biophysical (AP): Vegetation, land units Policy driven: National laws, regional policy, land utilization types, participatory planning decisions, cadastre	Coordinates Geometric lines Pattern and tone Pattern and tone of exploited areas Geometry

However, the study reveals that obtaining a clear definition and mapping formal units for livestock farming based on local perceptions is very difficult. The activity in the area is based on two main livestock farming systems. First, a semi-sedentary grazing system is practised by the agro-pastoralists/herdsmen, who have relatively large herds (39 in total in the area). They mostly use the bush areas, located in the multifunctional agri-sylvo-pastoral zone, and the fallows. Secondly, a semi-intensified sedentary livestock production system is practised by the agriculturalists (native and migrant), who keep small herds, including draught and ploughing animals. They mostly use the fallows and interfield areas. In any case, the study shows the strong dependency of the livestock-farming units on the dynamic of the agricultural lands.

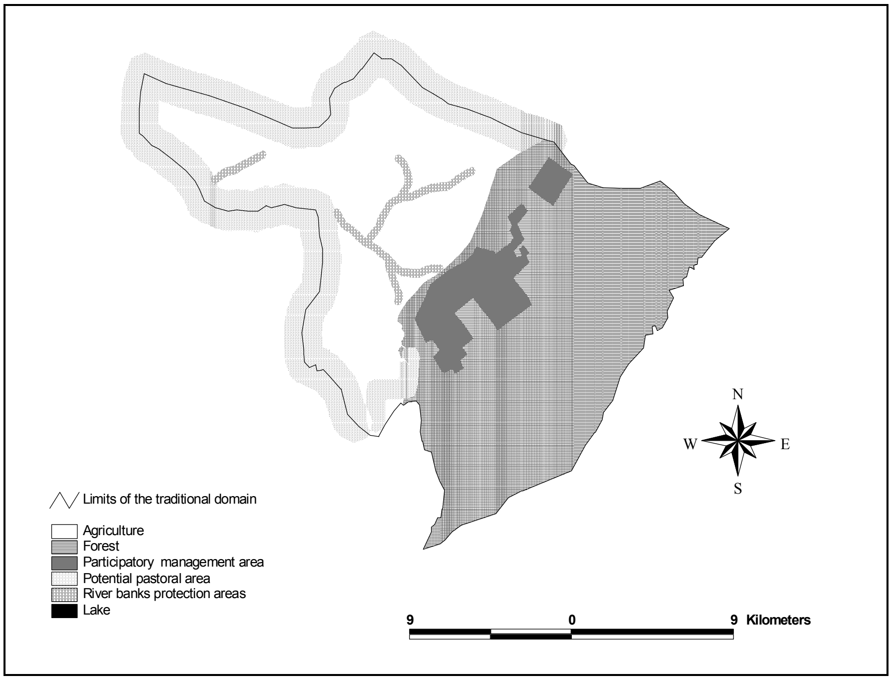


Figure 2.6 Possible re-composition of the land use zone according to the different management driving factors

Because of the importance of this dynamic due to the high population pressure, the criteria traditionally used by the local community to define the pastoral units, such as soil (marginal lands), topography (hills), distance (remote bushes), are increasingly ignored. Rather than a spatial analysis using PRA and conventional data, a more in-depth process, involving negotiations among the different groups and taking into account the needs and constraints of all stakeholders, is necessary to match the need for defining a formal unit for the activity of livestock farming – as emphasized by the PRA tools (diagram of production system). Here too, PRA plays an important role by providing the relevant socio-cultural and economic information necessary to support the mapping process with GIS. The definition of the forestry management units was facilitated by the existence of formal geographic entities with known boundaries (forests, rivers). The criteria defined by the policies and participatory planning procedures were easily converted into mapping criteria, using the spatial functionalities of GIS.

2.5 Conclusion

The results presented in the present study illustrate how the local land management system is strongly related to the socio-cultural, economic and biophysical incentives and knowledge of the local and regional stakeholders. This supports the study of Reenberg et al. (1997), which concluded that the ethnic-specific perceptions of the natural environment influence agricultural strategies, and the ethnic differences determine how natural resources are exploited. The statistical analysis proved that qualitative information collected at group level from a PRA survey is significantly representative of the detailed quantitative data collected through a household survey. PRA data can therefore be a strong basis for understanding land use strategies and identifying the different factors that influence the definition of local management units for further processing in a GIS. Although the socio-cultural and economic factors are important for the planning process, they were not found significant enough to systematically justify separate definitions of management units at the community level. They should, however, be taken into consideration when analysing other factors (such as conflicts) that could compromise sustainable management activities. Agriculture is the most important traditional activity of the native people, and its related constraints were found to be the most important internal factors determining land use activities and land management units. By tradition the livestock farming units are residuals of agricultural units, and stable units can only be defined through the participatory planning process. Forestry is also an important activity – which was emphasized by the external factors – for improving both the economic and environmental situation in the area. Spatial modelling in a GIS environment proved to be capable of defining and mapping the management units relevant to the stakeholders involved in the village land management process. The data acquisition techniques used by the project (PRA and photo interpretation) proved sufficiently relevant to support the ongoing participatory planning process.

CHAPITER III* *

INTEGRATION OF LOCAL PARTICIPATORY AND REGIONAL PLANNING: A GIS DATA AGGREGATION PROCEDURE

*This Chapter is based on Sedogo, L. G. and Groten, S. M. E. Integration of local participatory and regional planning: a GIS data aggregation procedure GeoJournal *(in press)*

Abstract
This chapter presents an approach for GIS integrating local participatory land management information used for regional planning, and contributing to a bottom-up approach to land use planning. In participatory planning, the integration between local and regional levels should facilitate the communication and co-operation among the parties at both levels, for an efficient use of available resources. For coherently linking these two levels it is necessary to transform the data produced at one level, in order to be usable by the other. This transformation consists of a spatial procedure, which allows scaling-up the local participatory rural appraisal (PRA) information for regional purposes and scaling down the regional information for local use, using a GIS. Such an integration procedure is presented and discussed using data from a case study in southwestern Burkina Faso.

KEY WORDS: GIS, Land management, Participatory planning, Regional planning, Participatory Rural Appraisal (PRA)

3.1 The challenge of integrating different levels in land use planning

The intent of this chapter is to present an approach for integrating local participatory land management in regional planning using GIS, and contributing to a bottom-up approach to land use planning. Integration issues are highly critical in regional planning and including local information from participatory planning was highlighted as a condition for sustainable resource management (UNCED, 1992; FAO, 1995). Integration in regional planning aims at linking the micro level of management (i.e. farm, community land) and the level of policy making (sub-national to national). In land use planning, the problem has more often been approached by studying the interactions between the biophysical and socio-economical elements of a land use system (Fresco et al 1990; V. Duivenbooden, 1995; Mohamed, 1999). For this, multidisciplinary procedures, tools and techniques have been developed for analysing and evaluating the impact of socio-economic activities on the eco-system as well as the relevant effects of the state of the eco-system on socio-economic activities (Mohamed, 1999).

However in a participatory context, the data integration should rather facilitate the communication and co-operation among the parties at both levels (Luning, 1986). It should also contribute to promote a state of democracy of information, allowing genuine negotiations between local and regional stakeholders (Dent, 1997).
For instance, the integration of information representing the two poles should allow to:

- Ascertain the representation of the important local planning issues at regional level;
- Assure the feasibility of proposed local interventions, taking into account regional objectives and constraints (biophysical, socio-economical) as well as local knowledge, incentives and values;
- Provide local planners with decision-making tools for maximizing the potential of regional support (i.e. geo-data, financial, organizational, etc.), checking the relevance of regional /national plans to local communities and reducing land use planning conflicts.

A number of studies in the developing countries have indicated that bottom-up procedures are successful for improving the quality of regional planning and resource management (Ramm, 1992; Nurse et al., 1993; Walker and Sarkar, 1996). But despite the increasing interest in establishing conceptual frameworks including anthropogenic factors for analysing local to regional land use planning, examples of models linking local participatory and regional planning are very few (Gottlieb and Reilly, 1994).

Geographic Information System (GIS) can be used for integrating local to regional planning by adequately combining the different spatial levels within a holistic framework. The power of a GIS resides in its capability of handling large amount of spatial data and conducting spatial analysis. This involves (non spatial) attributes querying, spatial queries and generation of new data sets from original databases (Yue-hong, 1997). As stated by the Economic and Social Commission for Asia and the Pacific of the United Nations (1996) applications of GIS for resource management and decision-making is limited only by the imagination of how to combine the different data sets. O'looney (2000) illustrated this with different GIS applications supporting the local governments to improve the quality of public services, by addressing various questions that can be grouped as:

- Efficiency: improvement of public works, transportation, law enforcement, emergency and utility management, economic development;
- Equity: sharing resources in tax and budgeting, neighbourhood services, citizen participation and democratic processes, environmental justice;
- Community viability: Sound negotiations in land use planning, public health, housing, parks and recreation;
- Environmental quality: sustainability of environmental development, resource conservation, and policies.

In a multi-scale planning involving local and regional stakeholders, the GIS should answer specific questions to allow the fluidity of information on both levels: How do we integrate the knowledge, perceptions and needs of all the stakeholders and translate them into feasible plans? How do we facilitate the negotiations between them by providing the relevant information to support decision-making at both levels? The procedure to establish such a system and its feasibility will be analysed in this article, from both a technical as well as a planning point of view.

3.2 The problems of integration in a participatory planning approach

During the eighties, the planning procedures in Burkina Faso evolved from the bureaucratic top-down to more participatory bottom-up approaches, based on the design and implementation of local land management / land use planning programs. The Structural Adjustment Program (SAP) introduced in nineties has also contributed to reduce the sway of the central governments and regional institutions in the planning process. Local people are part of active land management boards dealing with decision-making in planning, implementing and evaluating activities for sustainable development. In this new context adequate processes and data integration are very essential for a good communication between the two levels (see Figure 3.1). A convenient aggregation procedure should include local stakeholders' interests representing socio-cultural factors such as the tenure regime, political issues and many other critical local constraints. These local phenomena and situations apparently insignificant from a regional perspective may sometimes determine the success or failure of the planning process.

The classical aggregation methods used in regional planning are often confronted with the difficulties of scaling-up from the farm to the region level. Despite important efforts to improve the farm classification methods and develop convenient aggregation models (Driessen and Koinjn, 1992) satisfactory procedures are still lacking (Fresco et al., 1990; Rabbinge and Van Iteresum, 1994; Mohamed, 1999). Besides the technical problems usually invoked (Rabbinge and van Iteresum, 1994), many others appear in a participatory planning approach such as:

- The difference in perception and representation of space and spatial phenomena between local people and regional planners;

- The difference in data formats, capturing and modelling techniques: local PRA data and methods are in "soft systems" formats (Scooness and Thompson, 1994), while "hard systems" methodologies and data are used at regional level;

- The storage media and processing tools are also different, hence differences in data quality: While at regional level data are stored in modern standard formats (analogue and digital), the local level use more informal ways due to the oral tradition environment (e.g. sketch maps)

- The scale difference, often implying different representations of spatial objects: At local scale, a village territory can be represented as a region (area) while at regional level it can be represented as a point.

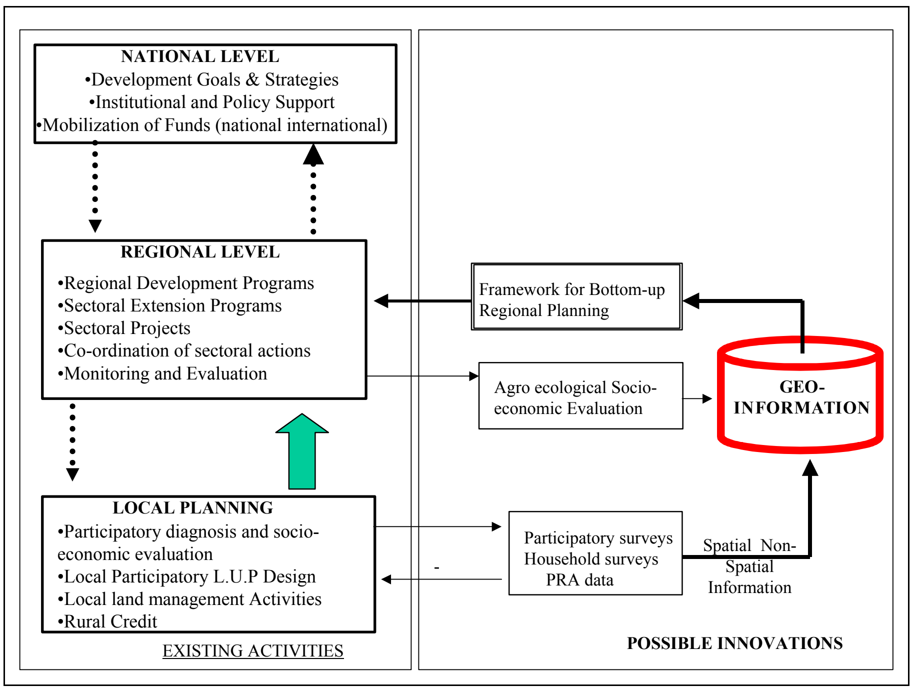


Figure 3.1. The planning context in Burkina Faso and the potential innovations in a GIS planning support system

Besides, institutional incoherencies and bureaucracy still strongly influence the relationship between the regional planners and the local communities. This contributes to the superimposition of different types of planning and management units (Table 3.1), generating land use conflicts. Operational methods for breaking down the regional implications (e.g. sharing regional constraints, budget allocation, transportation, etc.) are also lacking, affecting the soundness and feasibility the local plans.

Table3.1. Regional planning units with their possible impact on local management units

Regional Units	Local units	Nature of impact	Relative importance	Planning Action
Roads	Local forests	Deforestation	Low	Buffering
	Local plantation		Very high	Reallocation
Transhumance roads	Local reserves	Deforestation	High	Buffer corridors
	Pastoral lands	Overgrazing	Very high	Reallocation
Dams	Cultural sites	Flooding	Very high	Reallocation
	Local plantations	Flooding	Very high	
Reserve areas	Agriculture			
	Pastoral lands	Encroachment	Low to high	Reallocation
Pastoral lands	Agriculture			

The integration herein aims at a mutual support of the planning processes at both sides by supplying the relevant information out-coming from one level of planning as input information for the other. This means that the procedure should allow the best use of local information (mostly PRA data) into regional planning analysis and *vice versa*. Interest of using PRA approaches to support sustainable local planning processes has increased (Chambers, 1994; Grenier, 1998; v. d. Hoek, 1992, Waters-Bayer and Bayer, 1994). However, research that attempts to integrate local PRA data in systematic regional planning approach is lacking. This could be achieved through a spatial approach combining the different spatial levels in a holistic framework using a GIS.

3.3 The Proposed solution: A geo-information approach

The proposed approach uses a geo-data data abstraction procedure developed in spatial data handling theory (Molenaar, 1998). It is based on the use of the spatial distribution of specific information issued at one planning level, as a means of communication with the other. Considering the mutual support between the two levels, the integration is a bi-directional procedure (Figure 3.2) consisting of:

- A bottom-up procedure for a regional planning using a spatial abstraction method. It is based on the definition of the local land management units relevant to all stakeholders using local driving factors (derived from PRA and household surveys data), to derive the regional planning units (Loader and Amartya, 1999; Sedogo and Groten, 2000).
- A regional feedback to support the lower planning levels, using regional information during the local planning process. In this instance, the local planning units are defined during participatory surveys, using georeferencing tools such as topographic maps, global positioning system (GPS) or aerial photographs, together with local knowledge.

Because of the differences between the two systems, a transformation is necessary to convert the data generated on one side (e.g. sketch maps), into a compatible usable format on the other. In order to do so, we represent the planning units at a particular level (i.e. local level) as spatial features in a GIS (points, lines or polygons), with their attributes pertaining to the different dimension of land management system (biophysical, economical and social-cultural). According to the nature of the attributes data of these spatial objects, their scale and type of measurement, specific GIS transformation functions can be used to perform the spatial conversion, for scaling-up or down the information. Such a procedure enables the determination of the spatial impact of any planning information on one level, over the (planning) units on the other level. The principle of encapsulation and other properties of the object-oriented data model (Molenaar, 1993; Tang et al., 1996) allow flagging the information for an easy retrieval and use in the procedure. This spatial approach to integration was implemented and tested for linking local participatory and regional planning in a case study in Burkina Faso.

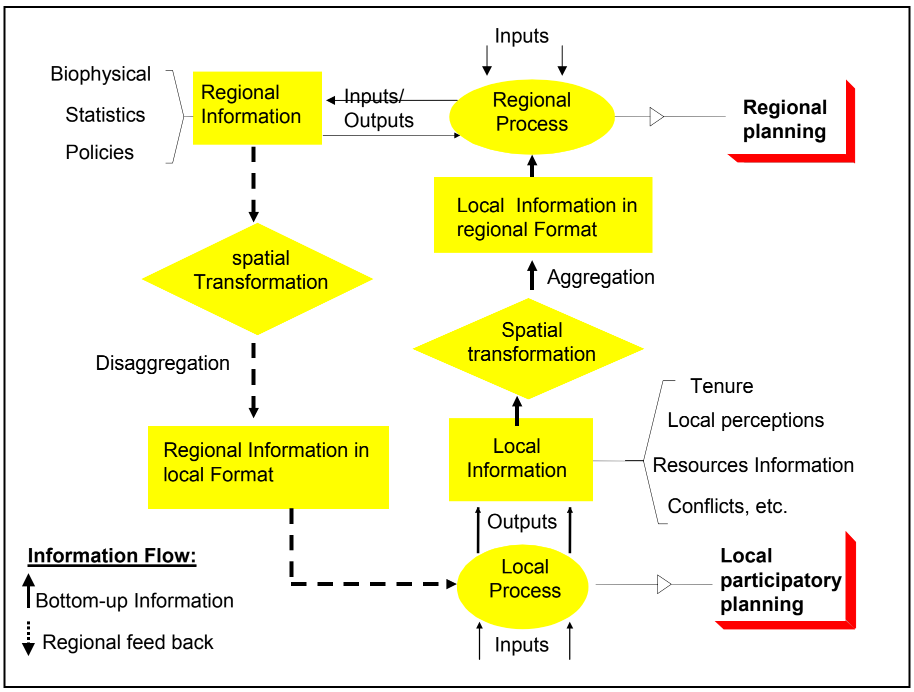


Figure 3.2. Data transformation procedure for integrating local and regional planning processes

3.4 case study in western Burkina Faso

3.4.1 Presentation of the study area and the cases

(1) The study area

The study area is the province of Houet located in the south west of Burkina Faso (Figure 3.3). The annual rainfall ranges between 800 and 1200mm and the main cropping systems are rainfed cultivation (extensive cereals and semi-intensive cotton), irrigated rice, fruit trees and small-scale market gardening. Extensive livestock farming is increasing due to clearance of the tsetse fly, the contribution of cotton revenues and the impact of migration from the arid northern areas. Despite the area being relatively wealthy in terms of natural resources as compared to the rest of the country, it is severely degrading due to a combination of factors. These factors indicate a high population growth, an increasing livestock number, an important immigration, an important impact of traditional tenure systems, archaic farming systems and inappropriate land use strategies. For that reason, the province was chosen as a pilot to start implementing a community-based land management approach. A participatory land management program financed by the World Bank was initiated in 1992 with the objective of conducting a sustainable land management based on a participatory planning, while improving the local social conditions by increasing the household revenues. Based on the remarkable results of this experience the government started at regional scale a sustainable land management program for the period 2001- 2006. Two cases were used for studying the local to regional integration.

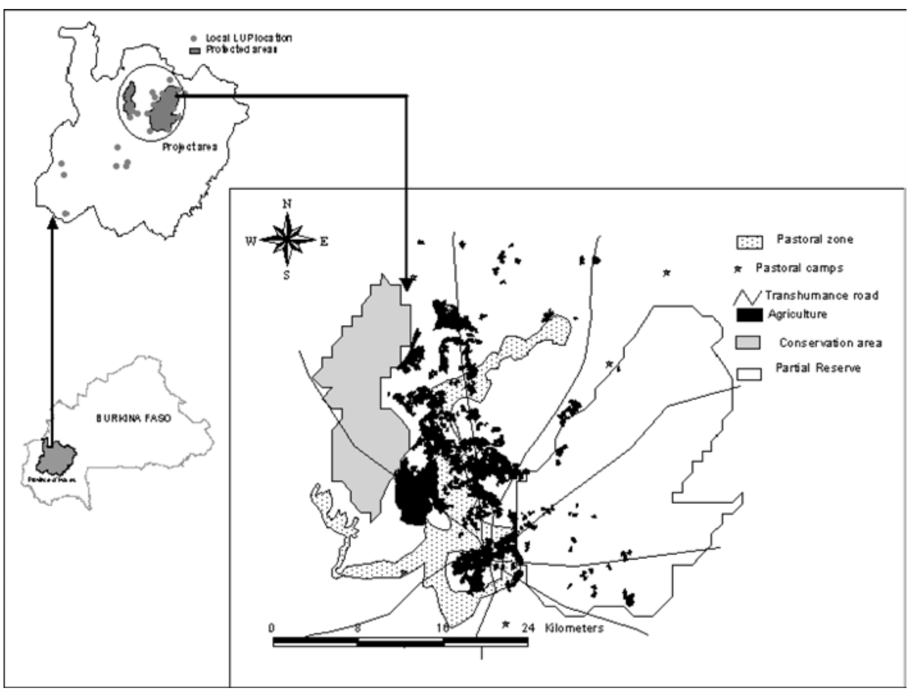


Figure 3.3. The study area: Location of local use plans (LUP) and the land use map in the project area.

Case1: Integrated land use planning at semi-regional level
The Forest of Maro and the Hippopotamus conservation lake are two protected areas located in the north west of the province. During the pilot phase of the project (1992 – 1996), an integrated land use plan was initiated in that area, with the following components:

- A participatory management of the Maro forest by an inter-village committee representing 17 villages surrounding the forest with multiple objectives of income raising for the local people, supplying fuel wood to the province capital, and the conservation of the forest;

- The creation of a stable pastoral zone to secure the pastoralists living in the area while avoiding the increasing pressure of cattle on the reserve areas;

- The protection of riverbanks against soil erosion and sedimentation;

- The definition of local conservation areas to protect the village cultural sites.

Case2: Bottom-up regional planning based on local participatory planning information
In preparation for the actual phase of the program (2001-2005), the regional office of PNGT implemented a participatory diagnosis in 12 test villages during the year 2000. This step provided the regional planners with relevant information that should serve as basis for an implementation at provincial scale by:

- Efficiently supporting the local planning procedure at regional scale;
- Efficiently articulating the local plans with regional formal planning activities;
- Allowing scenario building at regional level in order to orient sectoral strategies based on the most relevant local planning information.

3.4.2 Methods

(1) Local PRA surveys and data
PRA surveys were conducted in three sample villages in the neighbourhood of the Maro forest, aiming to understand the biophysical, socio-cultural and economical factors related to the management of the natural resources in the area. The land use zones agreed between the villages in the project area were delineated from a photo-interpretation. They were geo-referenced during participatory field-check, using topographic maps and hand GPS. In addition, secondary PRA data were compiled from surveys carried out by the project in 12 villages. Ancillary data were also collected near the regional services. They included biophysical and socio economic data at provincial level, and a village level socio-economic database of the province. A land cover map of the project area was derived from the interpretation of a 1:25000 scale air photograph. Digital elevation model and a slope map were generated by interpolation using contour lines digitised from a topographic map at scale of 1:200000.

(2) System development and data modelling for multi scale land use planning
To support a multi scale land use planning model, an information system (Davis and Olson, 1985) was developed in order to get a holistic framework of the land management system from both local and regional perspective. It combined a "soft system methodology" (Checkland & Scholes, 1990) with a structured system approach enabling the technical integration of the local knowledge collected from PRA into the system design. The information needs for the system were obtained by analysing the land use planning problems at both levels. PRA methods were used to determine the boundary and the components of the local land management information system (biophysical, social-cultural, economical sub-systems), their interrelations and input/ output data. Interviews were also conducted with regional planners to define the upper boundary (regional level) of the system. A Business System Planning (BSP) technique (IBM, 1984; Davis and Olson, 1985) was implemented to define the architecture of the integrated planning system. Conceptual modelling was used for structuring the system, according to the users' perceptions, based on the terrain-object approach (Molenaar, 1993; 1998). Different spatial layers were created, including local as well regional planning information (biophysical and socio-economical data, regional planning units such as reserve forests, transhumance roads, cotton gathering network, settlements etc.).

(3) Spatial analysis
The spatial analysis aimed to identify and overcome (or at least reduce the effects of) the main bottlenecks to the implementation of the local management plans. It was based on a spatial abstraction procedure (object classification and aggregation). Based on the concept of terrain-object representation (Molenaar, 1993), we used the entity "village" (represented on the regional map by point features) as the lowest elementary object. Attribute data were used to create different GIS attribute maps. For analysing the socio-economic data, knowledge of village boundaries was required (political /administrative). In absence of an existing map we simulated temporary artificial boundaries using "Thiesssen polygons". The PRA data were analysed to determine their relevance and possible contribution to a GIS based planning system. We identified three main factors with spatial impact as being able to create conflicts between local and regional planning activities:

1. Activities at regional level threatening the sustainability of local planning units: The sustainability of the pastoral zone near the Maro forest was analysed with regard to the spatial impact of local constraints and the seasonal cattle migration (transhumance).

2. Specific socio-economical constraints to the implementation of the local land use plans at regional scale: For instance, the implementation of several labour intensive or profitable activities during the same period at local level may face multiple constraints: time, labour availability, weak coordination among regional partners, etc.)

3. Access to the land by the different groups of stakeholders: Access to land was used as a limiting factor for the sustainable management of the local natural resources at a regional scale. We classified the tenure regimes by combining different variables included in the village level database (see Table 3.2), as following:

Table 3.2: Types of tenure regime derived from local information

Tenure regime	Status of settlement	Legal status	Land Owners	Dominant population	Legal and traditional land rights
1				Native population	Legal, full access
2	Village	Administrative	Native people	Migrant farmers	Legal with Limitations in land management
3				Pastoralists	Non secured access
4	Cultivation			Native population	Full access
5	hamlet	Illegal occupation		Immigrant farmers	Illegal and limitations in land management
6	Pastoral camp			Pastoralists	Illegal, non secured access

a. *Village status:* (1) the administrative villages with legal land rights; (2) cultivation hamlets (3) pastoral camps having illegal status;

b. *Traditional land rights*. These are based on the land rights conferred to the most important ethnical group in each settlement according to its' social origin, established as follows: (1) the natives having full rights, (2) the migrants agriculturalists having some limitations and (3) the pastoralists facing high land insecurity (Sedogo and Groten, 2000);

c. *Conservation areas* (state properties forbidden for local population): (1) yes; (0) no.

d. Irrigation schemes and reserve forests are state properties on which local population; (or co-operatives) may have legal use: (1) yes; (0) no.

We used the biophysical data to test the validity of some local agricultural and land management strategies at regional level, based on local perceptions and knowledge on the biophysical environment. Sedogo and Groten (2000) have determined that the farmers in the study area define their preferences for land management units according to topography (essentially in view of flood risk), slope and soil texture. This information was used to derive different terrain units using the DEM as the following: (1) the lowlands (height ranging from 299 to 320m); (2) undulating glacis plains; (3) the upper plateaus and hills (above 360m). The slope map was also classified as following (slope ranging between 0 and 23% in the area): (1) the flat areas with less than 2% (flooding zone); (2) gentle slopes (from 2 to 7%); (3) the steeper slopes above 7%. By overlaying the different layers with the village base map in a GIS, each entity (village) inherited the related information as attributes from which the spatial abstraction procedure was performed.

3.4.3 Results and discussion

(1) Evaluation of Information from PRA for GIS input

a. Format and relevance of the PRA data for regional planning

The local planners showed a high ability in using PRA methods. Table 3.3 gives a synthesis of the different types of information collected at local level from PRA and their possible use in local and regional planning processes. As compared to other methods used in rural surveys, PRA is distinguished by the use of local graphic representations created by the community, which legitimise local knowledge (Grenier, 1998). The analysis of the PRA information in different formats (sketch maps, scoring matrices, diagrams and models) in terms of spatial, thematic and temporal relevance for a GIS-based planning system is shown in Table 3.3.

Table 3.3. Type, relevance and potential use of PRA data in the study area

Information type	PRA Tools	Data	Use in local panning	Use in regional planning
Thematic	Matrices Diagrams Semi structured Interviews	Ranking Main processes; relationships; system components; thematic attributes,	System analysis and design; application models; conflicts; socio-economic driving factors	Planning objectives; weight maps; information requirement; application models; databases;
Temporal	Calendars Historical profiles	Land use dynamic; time planning	Land use changes; conflicting activities	Land allocation, planning alternatives; resource allocation models
Spatial	Sketch maps; transect	Management units; land use zones; biophysical data	Mapping; land use planning;	Spatial database

b. The thematic content: a reliable base for participatory modelling

As pointed out by Mascarenhas and Kumar (1991) quoted by Chambers (1994), participatory modelling and mapping have been a striking finding of PRA. Local people for designing comprehensible models of land management systems use different flow diagrams and models. In the present case different PRA tools were mainly used to: (a) define the local system boundaries and their external links using Venn diagrams; (b) identify the input output data using the exchange flow diagrams and (c) identify the local land management processes and their interaction using the diagrams of systems. This allowed structuring the land management system around the Maro forest as follows.

- *The forestry management sub-system*: The local forest is a reservoir of resources for the villages and the city (fuel wood, medicinal plants, fruits, etc.) and an important source of income for the farmers.
- *The of agricultural management sub-system*, Agricultural lands symbolize food security and economic wealth for the farmers. The inputs from the villagers represent labour, seedlings, equipment and land management activities (soil conservation manure fertilising, and ploughing).
- *The pastoral management sub-system*: The definition of pastoral units symbolises not only the stability and security for livestock farming, but also the improvement of agricultural systems through fertilisation.

- *The surface water management sub-system*: The water reservoir is an essential complement for livestock farming (watering), but yet has no interaction with agricultural activities (the dam was recently built in 1998).

c. The spatial quality

Participatory mapping was used for (a) inventorying the natural resources available in the village territories; (b) mapping the main management units; (c) referencing the landmarks limiting the villages (see Figure 3.4 in appendices). As in conventional mapping, different features are used for representing the spatial information. Their geometric quality is generally low and georeferencing by means of a GPS or topographic maps is a prerequisite for GIS input. For instance, landmarks are highly reliable and should be used to complete conventional local mapping (e.g. delineation of boundaries, identification of infrastructure). Despite their high thematic quality, lines and areas are very poor for localising spatial phenomena. Geo-referencing requires crosschecking by different groups of resource persons (elders generally). The combination of sketch maps with enlarged air photographs at scale 1:5000 by the local people as recommended in Groten (1997), proved to be useful for defining of local land management units.

d. The temporal aspects

Two main temporal information types were extracted from the PRA data: (a) long-term trends shown by historical profiles (land use dynamics, resource degradation) and (b) short-term information generated from activity-planning calendars (crop calendars, land management activities, etc). As shown by the activity-planning calendar in figure 3.5, the implementation of agricultural production, as the unique activity in half of the year indicates its importance for local people. The number of activities implemented during the dry season (November-April) is an indicator of a potential time constraint.

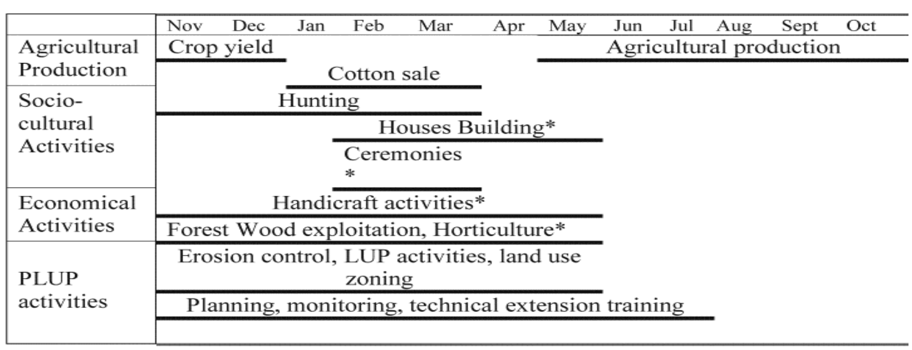


Figure 3.5. Synthesis of activities implemented yearly in the different villages as obtained by PRA. (*): Activities with no significant spatial impact

(2) Integrated land use planning around the forest of Maro

Different classes of spatial management units were identified in the area and characterized as follows:

- *Individual / farm level management units* (such as soil and water control, fertilising and agro forestry) are defined on the agricultural lands. Because of their relative small size at semi-regional scale they were merged in the cultivated lands that can be mapped from photo interpretation.
- *Village-communal management units* are composed of new forest plantations, local cultural sites (converted into local reserves), protected riverbanks (plantation of trees, shrubs and herbaceous species) and small irrigation schemes. Even though they are difficult to represent on a semi-regional scale, the principle of encapsulation offered by the spatial database makes them easy to be retrieved.
- *Inter-village management units* represent mainly the pastoral zones, forests surface water bodies and reclamation of flooding lowland areas.

The spatial analysis in the GIS by overlaying the new pastoral coverage with the terrain units map, the slope map and the land cover map allowed to determine the biophysical constraints on the planning process as presented in figure 3.6.

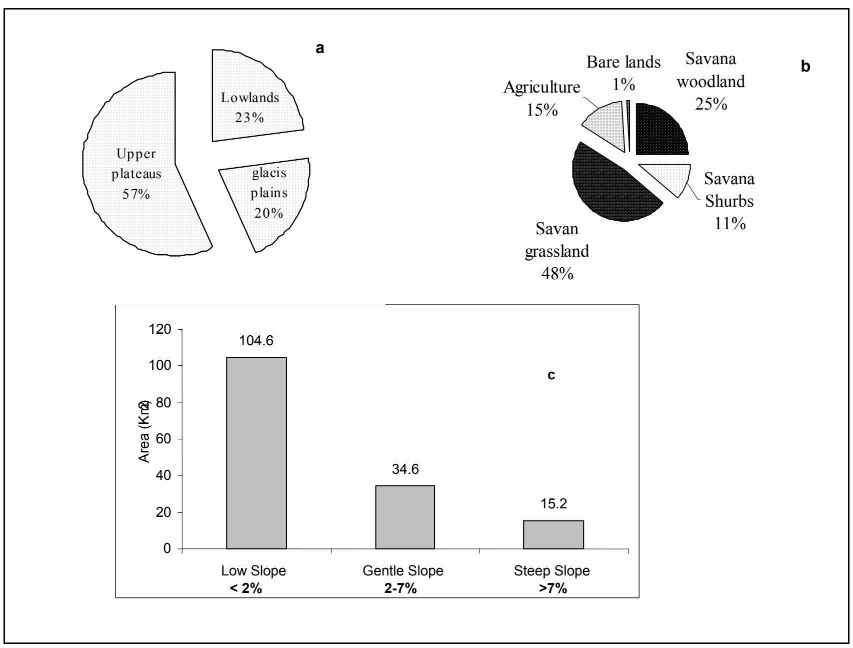


Figure 3.6. Distribution of the pastoral lands according to different terrain units, slope and cover types

The figures 3.6a, 3.6b and 3.6c show the spatial distribution of the different land / cover land use types and the terrain units in the project area. As shown in Figure 3.6b, agriculture is encroaching on the new pastoral zone (15%). This suggests an ongoing negotiation process for reallocating new lands to the people who used to cultivate in that area. Figure 3.6a shows that nearly 80% of the pastoral zone corresponds to lands for which the farmers have little interest for agricultural purpose. This indicates that somehow, the planning process has generated a clear physical boundary between these two conflicting systems and gives more security to the pastoralists. Thus, a bottom-up procedure contributed to define the new pastoral zone, by integrating the local perceptions, knowledge and objectives in the planning process. This shows that the spatial aggregation procedure can be reliably used for linking the two levels of planning.

From a sustainable management perspective, the analysis gave the following picture: Given a cattle number of 13300 Tropical Livestock Units (TLU) for all the villages involved in the local planning (source Projet RESO, 1998) the carrying load was estimated nearly at 87 TLU/ km^2 in the new pastoral zone. According to the regional statistics, the average rangeland load is nearly 31 TLU / km^2 for the province. However, based on of the potential biomass production for this agro-ecological zone estimated from ground surveys (Boudet, 1991) we can expect a theoretical sustainable carrying capacity of nearly 100 TLU /km^2. This shows that the bottom-up procedure can be reliably used for defining sustainable planning units at semi-regional level.

(2) Local planning information as input in regional planning

The analysis of the synthesis of the land management activities foreseen in the different villages for the planning period (Table 3.4) shows the following scenarios:

- On average, each village has to manage nearly 100 ha of soil and water conservation areas and 160 compost pits. According to estimates and the norms recommended by the National Agronomic Research Institute (INERA), the average production of compost in each village covers 300 ha of fields. Based on conclusions of studies on yield estimates using organic fertilizing in Burkina Faso (Maatman, 2000; Dugue, 1989), and given that the average yields of maize and sorghum in the study area are respectively 1.7t and 1.2t per ha, we could expect an increase of more than 400t of cereals in average per village. Based on the national norms of food security this represents food consumption for nearly 2100 persons per year. Because agricultural production in this part of the country is already self-sufficient, this means that more food can be redistributed in shortage areas (central and northern parts of the country).
- The protection of riverbanks against sedimentation and the plantation of new forest plots are relatively modest as compared to agricultural management activities. However, 50% of the villages expressed the need to protect their cultural sites, which are converted into local conservation areas.
- The number of artificial lakes needed (50% of the villages) reveals the importance of surface water control for the population and reflects the constraint of water shortage for cattle watering, fishing and small-scale irrigation during the dry season.

- For most of the villages (67%) pastoral zoning is a very important activity during the five-year plan. It aims at defining a stable unit for the activity and more importantly, solving the conflicts between farmers and pastoralists.

Table 3.4 Activities to be implemented in 5 years local plans by villages in the study area

Villages	Population (1995)	Estimated land (ha)	Soil conservation (ha)	Compost pits (Number)	Construction Water reservoir	Lowland reclamation (ha)	Protection River bank (Km)	Plantation Forest plots (ha)	Construction Vaccination parks	Local roads (km)	Delineation of Pastoral zone
Kadomba	5700	6000	150	125	1	25	20	40	0	0	1
Balla	3045	4591	100	100	0	20	0	3	0	0	1
Dafinso	1200	2716	20	50	0	100	20	13	1	0	0
Banakeledaga	2720	1586	100	150	1	0	0	0	0	0	0
Diofoloma	3200	4356	200	100	0	0	20	23	1	7	0
Sembleni	400	9855	50	75	1	0	0	3	0	0	1
Gognon	600	6110	75	75	0	0	10	18	0	0	1
Pala	1070	6196	20	50	0	0	0	45	0	2	0
Yegueresso	1540	1083	50	75	1	0	0	10	0	0	1
Niamadougou	1000	1693	50	350	1	0	0	0	0	2	1
Toussiana	6640	3164	250	650	1	0	0	0	2	32	1
Ramatoulaye	900	2500	100	75	0	0	0	0	0	0	1

(3) Planning constraints in regional Bottom-up procedure

The essence of the regional planning aims to identify and overcome (or at least reduce the effects of) the main bottlenecks to the implementation of the local management plans. These bottlenecks reflected by the local planning constraints, were identified from the analysis of the PRA data.

a. Impact of tenure regimes

The tenure regimes previously defined were used to create a GIS layer as shown in figure 3.7 and used to gauge the feasibility of land management activities at a regional scale. The figure 3.7a shows that the portion occupied by a dominant immigrant population represents in total 50% of the land. This points out the importance of immigration in the area, and its impact on sustainable management. The total area occupied by a dominant immigrant-agriculturalist population only represents 42% of the land. The pastoralists control only 8% of the land, which is in proportion negligible as compared to the other groups.

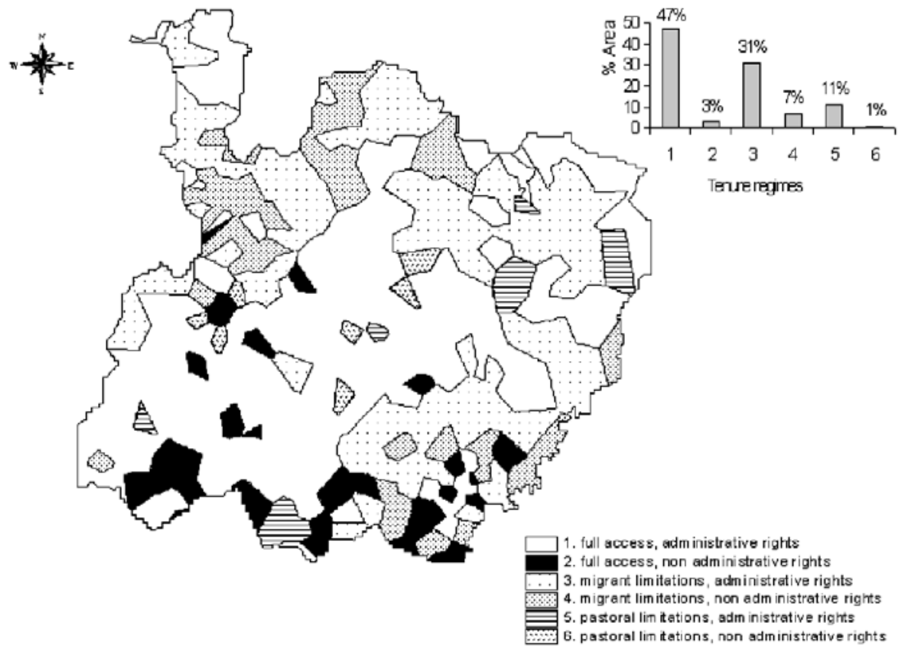


Figure 3.7. Distribution of the different tenure regimes and their importance at regional level

b. Impact of economic factors

From the activity calendar in Figure 3.5, potential labour shortage was identified as an important constraint in relation to the motivation of local people for land management activities and their involvement in profitable activities. For instance, wood exploitation is highly profitable for the villages surrounding the Maro Forest. An inter-village committee of forest workers is exploiting 1200 ha of the forest planted with exotic quick-growth tree species (*Gmelina arborea, Eucaliptus camadulensis and tectona grandis)* according to a plan implemented since 1996. Because of its success, the participatory forest management has become an important component of the regional strategy of firewood supply to the city of Bobo-Dioulasso. The regional forestry service has defined a buffer zone of 80 km in which, villages are authorised to exploit the contiguous national reserve forests. Table 3.5 gives the statistics for the revenues of the villages, of which a global net benefit was estimated at nearly 150 million CFA. In comparison, these revenues correspond to the production of more than 1500 ha of cotton for the same period (the price of cotton was 105 CFA francs per kg for an average yield 915kg/ha). The time used for wood exploitation overlaps with the implementation of intensive labour requirement activities (erosion control and fertilisation). For instance, the labour requirement for building the small dikes to reduce the speed of water ranges between 50 and 120 men-day/ ha (Maatman, 2000 p250). Thus in practice, the feasibility of the local plans for potential wood exploitation areas is hampered by this problem of motivation and labour shortage.

Table 3.5 Statistics of wood exploitation for the 17 villages around

		Lowest village revenues	Highest village revenue	Average	Total revenues for all the villages
Revenues of the wood exploitation (CFA)		*183600*	*28955955*	*6102273*	*147235370*
Comparative size of area needed for crop production (ha)		Min area	Max area	Average area	Total area
	Cotton	2 ha	301 ha	64 ha	1530 ha
	Maize	3 ha	432 ha	102 ha	2454 ha
	Sorghum	5 ha	724 ha	152 ha	3681 ha

Likewise, the information from Venn-diagrams and interviews revealed that the proximity to irrigated cash crop areas (sugar cane, rice) and the industrial centre in Bobo-Dioulasso is also a source of labour shortage and lack of motivation for implementing land management activities. Most young people from the neighbouring villages (5 to 10 km easily covered daily by bicycle) seek seasonal jobs in these areas.

Using this information, we could identify through the GIS analysis the areas where potential labour shortage may occur due to overload of land management activities. It was used as an aggregation factor to identify the areas possibly affected at the province level and where logistic planning is required (checking for the real needs with local committees, coordination of actions between several regional partners, providing additional support to the implementation of the local plans, etc.).

c. Impact of Regional planning units

Regional units such as transhumance roads should be considered in local planning procedures. The province is mostly a transit area and this cultural practice can contribute to the failure of rangeland management activities: (overload of watering and rangeland carrying capacity, diseases, conflicts, etc). According to the land reform in Burkina Faso, a buffer zone of 500m should be created along these roads to protect resources in the transit areas. However in practice, a vast corridor is affected by the grazing, right up to the final destination. From GIS analysis, the areas possibly affected by the transhumance grazing were selected.

(4) Definition of regional planning units by a spatial abstraction procedure

Figure 3.8 shows the results of the bottom-up procedure based on a spatial abstraction. The overlay of the village territory coverage with the layers above described generated a new spatial database that was used to perform the aggregation procedure for regional planning. A spatial database contains data that represent in principle elementary statements, which often refer to the relationships between objects and geometric or thematic data (Molenaar, 1998). In the present situation, the overlay operation added to each village entity a set of attributes representing the different constraints defined above.

Queries were performed in this new spatial database, to derive regional objects representing specific regional planning patterns. Class generalisation and object aggregation (Molenaar, 1993, 1998) were done based on Boolean operators (“AND” and “OR”).

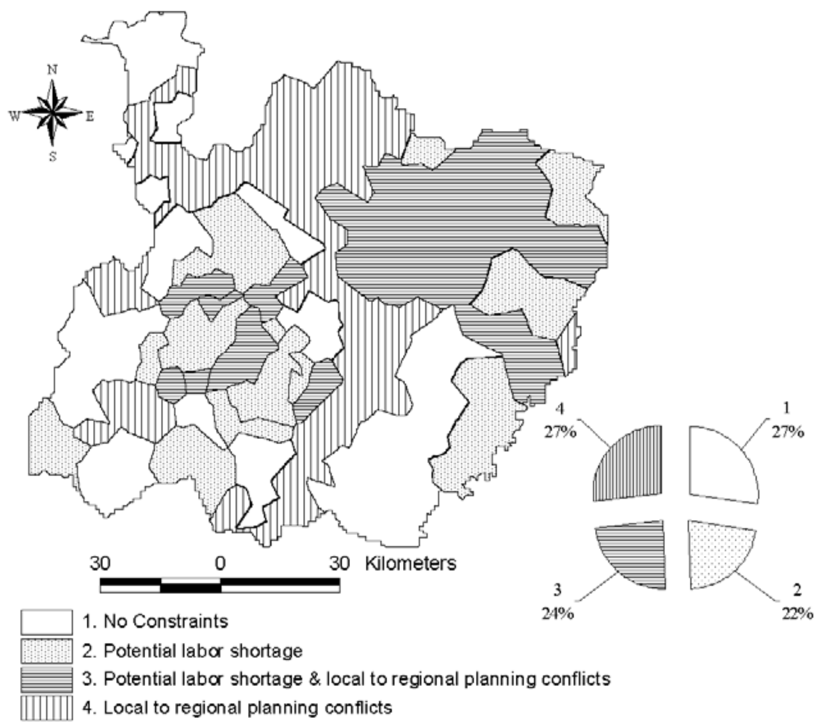


Figure 3.8 Result of a bottom-up spatial procedure in regional planning

This allowed selecting the elementary objects from specific attributes, which were used to recompose (reclassification or aggregation) the regional planning. Thus, based on the local information collected from PRA at local level, different orientations could be given to the regional planning. The results of the aggregation procedure show in Figure 3.8 that 27% of the province territory is not affected by any of the constraints mentioned above (excluding the issue of access to resources determined by the tenure regimes). Almost half of the province is facing either a potential labour shortage for implementing land management activities or potential local to regional planning conflicts. Less than 25% is facing both constraints. Based on these results, different scenarios can be explored by the regional planners to support the local plans. We can conclude that from a land use planning perspective, the spatial aggregation procedure aids real communication between the local and the regional levels.

3.5 Conclusion

The case study has shown that the method of GIS integration was useful for spatially linking the local participatory and the regional levels of planning for sustainable resource management. From the planning perspective, the bi-directional procedure proposed by the study offers an iterative way for providing the relevant information issued from one level, in a spatial format that is usable at the other. The PRA methods provide a holistic way for better describing the local planning units, which are to be aggregated at regional level. The principle of data encapsulation used the in the spatial database enables to flag and retrieve the important specific local information which can be used when necessary.

From a technical point of view it was proved that PRA data (often considered marginal) could be reliably handled together with other conventional data in a GIS. However, despite its simplicity and flexibility (which is convenient for regional planning where GIS is often perceived as a sophisticated decision tool) more research is needed for addressing specific issues such as handling conflicts in sustainable resources management using relevant information from both levels.

Acknowledgement:
The authors wish to thank the staff of the PNGT project and the regional extension services in Bobo-Dioulasso for their support and collaboration during the field visit in the study area.

CHAPTER IV*

USING A GIS-EXPERT SYSTEM TO PREDICT LAND DEGRADATION AREAS IN BOTTOM-UP REGIONAL PLANNING

* This chapter is based on L. G. Sedogo, A. K. Skidmore, H. van Osten, S.M.E. Groten (*submitted):* Using a GIS-Expert System to predict land degradation areas in bottom-up regional planning. *The International Journal of Geo-Information Science*

Abstract
An expert GIS is described that maps land degradation areas at a regional level. Previous studies describe land degradation processes mainly in biophysical and biochemical terms. But in African countries, such approaches have not stopped the degradation. In the present study, socio-economic as well as biophysical aspects of land degradation are proposed based on local perceptions and participatory land management strategies. The expert system combines the knowledge of local people about land degradation (used as expert knowledge) together with biophysical, socio-economic and cultural factors to classify land degradation areas at regional level using Bayesian probability rules. To validate the expert system, we used *a priori* probability matrices built with the local people during participatory surveys in six sample villages in the study area. The same variables used for building and validating the expert systems were discussed together with local land management planning committees in an independent sample set of 50 villages and used as indicators for participatory land degradation mapping. The map produced by the expert system was tested against the results of the participatory mapping, yielding an overall accuracy of 82%.

4.1 Introduction

GIS techniques have been widely used for land degradation related assessment at various scales (Grunblatt et al., 1992; Mallawaarachchi et al., 1996). However, despite their ability to operationally integrate data from various sources, conventional GIS techniques are limited when one wishes to integrate human or expert knowledge into spatial analysis for more sophisticated processing of the data (Skidmore et al., 1996). Instead, authors have prompted the need to include the perceptions of the land user in methods and models for defining and assessing land degradation (Biot et al., 1989; Lindskog and Tengberg, 1994; Johnston, 1997), implicitly recommending expert systems as useful assessment tools.

Knowledge-based or expert systems have been successfully integrated with GIS in a diverse range of applications. For example, Skidmore (1989), Huang and Jensen (1997), and Moller-Jensen (1990) used expert systems for improving the classification of digital imagery and for mapping (Skidmore, 1989; 1996; Skidmore et al., 1991; Nair, 1999). Expert systems have been successfully applied in the field of natural resource management and environmental modelling (Engel et al., 1992; Rosa et al., 1993; Merchant, 1994; Fedra, 1995). Some attempts to use expert systems to address land degradation issues include Balachandran and Fisher (1990) and Balachandran (1995) who developed prototype expert systems to advise on land degradation control and land conservation in South-eastern India. Boardman et al. (1990) used EPIC, an expert system, to assess the effects of climate change on soil erosion in England and Wales. However, applications attempting to integrate technical and local knowledge in land degradation assessment for the purpose of participatory planning are lacking.

The objective of this study was to develop an expert GIS for predicting land degradation areas at a regional level using information collected from PRA (Participatory Rural Appraisal) surveys in western Burkina Faso. The procedure combines the knowledge of local people on land degradation (used as expertise), together with biophysical and socio-economic GIS data layers to predict areas of potential land degradation. Land degradation was mapped at a regional scale using the expert system and compared with direct participatory mapping in 50 villages based on the perception of the degradation from experienced local land managers after evaluating the ecological, economic and socio-cultural characteristics of their villages' territory.

4.2 Methods

4.2.1 Characteristics of the study area

The province of Houet is located in the Southwestern part of Burkina Faso, between 5^0 - 3^0 west and $10^0 30$ and 13^0 North. The climate is a transition type, between the Sudanian and the Guinean climates, with a six-month wet season alternating with a dry season. Analysis of the rainfall distribution shows a high inter-seasonal, spatial and inter-annual variability. The rainy season lasts from April-May to October with rainfall peaks in August ranging from 220 to 400 mm per month. The mean annual rainfall registered for respectively the most Northeastern station (Hounde), the central (Bobo-Dioulasso) station and the most Southwestern station (Toussiana) in the province were 913 mm, 1040 mm and 1143 mm for the period between 1960 and 1990 (Ouedraogo, 1993).

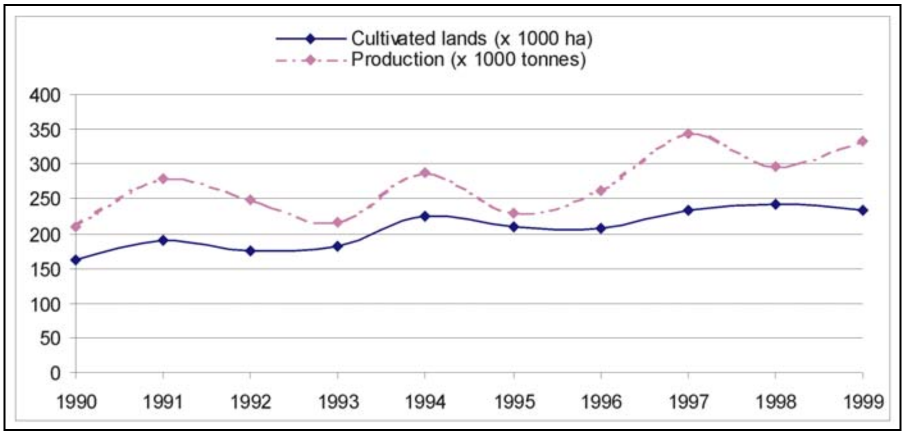


Fig 4.1. Evolution of the agricultural areas and production in the province between 1990 and 1999 (source: National Service of Agricultural Statistics)

Despite relatively low altitudes, the relief in the province is one of the most varied in the country, with heights ranging from 250 to 500 m. Plains and plateaus are the main terrain units. They are separated by a fault line (of nearly 150 m height), crossing the province from Northeast to southwest. According to Boulet and Leprun (1969) and based on the French soil classification system, (CPCS 1969) the main soil types are lithosols, tropical ferrugenous soils and ferrallitic soils. The high number of reserve forests in the province gives evidence of the relatively abundant natural vegetation compared to the northern provinces. It is mostly a savannah type composed of woodland, shrubs, grasslands and riparian forests.

Human and animal pressures on the natural resources are increasing due to a high population growth and extensive immigration from the central and northern parts of the country. The overall population of the province has tripled in twenty years, increasing from 306,670 in 1975 to 585,722 in 1985, and then to 935,345 in 1995 (source: national census). In 1991, the population of immigrants was estimated at nearly 40% of the overall population (source: regional planning service). This rapid population growth contributed to important agricultural land use changes. Between 1984 and 1999, the area under cultivation increased by about 75%, (from 131,700 ha to 233,800 ha). Despite this, the province is an important development area and was chosen a pilot area for implementing the *Gestion des Terroirs* approach. Based on the good results of a pilot land use planning project initiated in 17 villages (PNGT, 1993), an enlarged programme is targeting the implementation of the approach at a provincial scale.

4.2.2 Perceptions and assessment of land degradation in the participatory planning context

As noted in IFAD (1992: 23), the concept of soil and water conservation was not introduced to Africa by foreign experts. Local communities in all parts of the continent have used various "ethno-engineering" agroforestry and agronomic practices in response to problems of land degradation. The present study used the synthesis of participatory diagnosis carried out in 17 pilot villages preparing their local land management plans in order to infer the main indicators used for assessing land degradation. The indicators frequently cited by the villagers were crosschecked in the literature (Blaikie and Brokfield, 1987; IFAD, 1992; Oldeman et al., 1990; Grunblatt et al., 1992) to derive the variables that could be most reliably utilized for assessing land degradation at the province level (see Table 4.1).

Table 4.1: Local land degradation indicators, local perceptions and the data used for mapping

Variables		**Local perceptions on their impact on resource depletion**	**Data used (indicators)**
Physical variables	Soil fertility	Decrease in soil fertility indicated by change in soil texture (from loamy, sandy to gravely soils)	Soil map
	Soil erosion	Soil erosion resulting in river sedimentation and untimely surface water shortage in ponds and lakes in dry season	Farmer answers, slope map, rainfall erosivity map
	Slope	Important top soil removal in sloppy areas, contributing to decrease in organic content and gully formation	Slope map
	Vegetation depletion	Decrease in abundance of vegetation cover	Total biomass derived from NOAA NDVI data
Socio economic variables	Organic fertilizing	Lack of manure contributing to impoverishment of soil fertility and soil mining	Cattle /household derived from village statistics
	Traditional tenure system	High immigration increasing pressure on resources, but they have limited rights to implement land management activities	Tenure and immigration data obtained from village data
	Population pressure	Population density having high impact on natural resources, mostly reducing fallow period	Village population density
	Livestock pressure	Overgrazing due to increasing number of cattle	Cattle number (TLU)/ village
	Fuel wood demand	Increasing deforestation due to high fuel wood demand by urban population	Wood supply map to the city of Bobo based on distance map
	Institutional support	Lack of NGOs and services in villages is a limiting factor for land management	Derived from regional statistics
	Farming inputs	The distance to market influencing the farmers' capacity to purchase farming inputs	Map of distance to market places from regional database
	Land management	Presence or lack of local responses and coping capacity (implementation of land management activities)	Regional statistics

4.2.3 The expert system

4.2.3.1 General

Expert systems are computer programs that use knowledge to simulate the behaviour of human experts (Stock, 1989; Skidmore et al., 1996). Expert systems are composed of:

- A knowledge base that contains the data pertaining to a system to be modelled and rules (or relationships) linking the data and the hypotheses that are being solved. The data and rules are also often termed evidence.
- An inference engine, which uses the knowledge base to infer logically valid conclusions. It controls the order in which the rules and the data are considered.

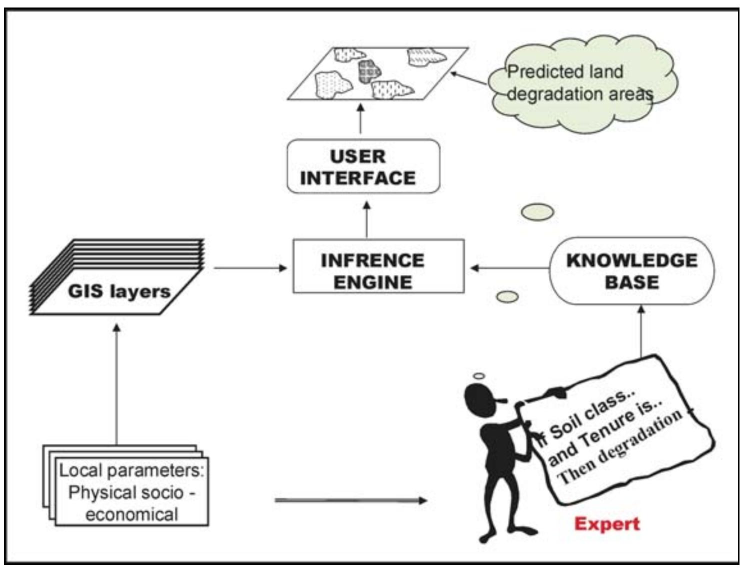


Figure 4.2. Components of an Expert System

The expert system used in this study is a Bayesian implementation as described in Skidmore (1989). The basis of the algorithm is that the likelihood of a hypothesis occurring, given a piece of evidence, may be thought of as a conditional probability. The information contained in the GIS layers is input into the expert system and matched with the information in the knowledge base. The research question to be answered by the expert system was: "Given land degradation classes existing in the province, what degradation type occurs at a certain location?" The sources of evidence are data derived from physical and socio-economic parameters (Table 4. 1).

Let L_a be a land degradation class occurring at the location XY (for $_{a = 1.....n}$ classes). Let E_b be the evidence of land degradation (e.g. cattle number, soil map, etc. for $_{b = 1......p}$

evidences). The expert system infers the most likely class using Bayes' theory, taking into account:

- The GIS layers from which the evidence was retrieved;
- The prior probability distribution $P(H_a)$ estimated by an expert;
- A probability distribution given some evidence E_b in an expert layer $P(E_b| H_{a,})$ which is estimated by the expert. Using Bayes' rules we can state that the probability that hypothesis $H_{a,}$ occurs at that specific location given a piece of evidence E_b , i.e.:

$$P(H_a | E_b) = \frac{P(E_b | H_a)P(H_a)}{P(E_b)} \quad (1)$$

As explained in Skidmore (1989) and Skidmore et al. (2001), $P(E_b|H_a)$ is the *a priori* conditional probability (Lee et al., 1987; Skidmore 1989a) that there is a piece of evidence E_b (for instance a steep slope) given the hypothesis H_a that class L_a occurs at the location XY. Because local people are not used to handling statistical data, we used a classification matrix to determine the weights (their subjective belief) that different evidence classes exert on land degradation; The weights were subsequently transformed into probabilities. On iterating with the different other items of evidence from the GIS database (b= $_{2, \ldots p}$), $P(H_a | E_b; b=1)$ (i.e. the *posterior* probability of H_a given E_b, for E_b =1) replaces $P(H_a)$ in (1). $P(E_b)$ is the probability of the evidence alone, or, the probability that any cell has item of evidence E_b such as steep slope. Bayes' theorem provides a formula to calculate $P(E_b)$:

$$P(E_b) = \sum_{a=1}^{n} P(E_b) | H_a)P(H_a) \quad (2)$$

The expert system developed for this study used forward chaining with a complete enumeration of the data (i.e. a blind search terminated by a running out of evidence).

4.2.3.2 The evidence layers for GIS input

a) Physical Indicators

- *a1. Soil map* A soil map of the study area at scale 1:500,000 (Boulet and Leprun, 1969) was digitised and classified in three categories (1: good; 2: moderate; 3: bad) according to the depth and texture of soil units.

- *a.2 Vegetation map:* Vegetation was mapped using NOAA-NDVI data (downloaded from the website of Africa Data Dissemination Service (ADDS) (*http://edcintl.cr.usgs.gov/adds*). The time series spanning the period between 1990 and 1999 was imported to the WINDISP software and clipped to the window corresponding to the coordinates of the study area. The images corresponding to the maximum NDVI for each year were extracted and their median values were classified into three categories (Values ranging from 0.1 to 0.6) Low vegetation cover: 0.1 – 0.2; moderate vegetation cover: 0.3 – 0.4; high vegetation cover: 0.5 – 0.6

- *a.3 Slope map:* Topographic contours were digitised from a topographic map at scale 1:200,000 and converted into a raster format. A digital elevation model (DEM) was constructed using a linear interpolation technique. A slope map was derived from an exponential hypotenuse function that calculates the slope in percent using the two differential (*dx* and *dy*) maps. The slope map (slopes ranging from 0 to 39%) was classified into three categories: gentle slope: <3%; moderate slope: between 3 and 10%; steep slope: >10.

- *a.4 Rainfall erosivity map:* Rainfall data for the period 1990-1999 from five meteorological stations located in the study area were obtained from the national meteorological service. The rainfall erosivity index (*R*) was calculated based on the Fournier Index (Briggs et al., 1989).

$$R = \sum_{12}^{1} \frac{r^2}{P} \qquad (3)$$

where: P = average annual rainfall
r = average monthly rainfall.

A rainfall erosivity map was generated, based on a point interpolation technique using a moving average filter. The final rainfall erosivity map was reclassified in three categories to generate the map shown in Figure 4.3

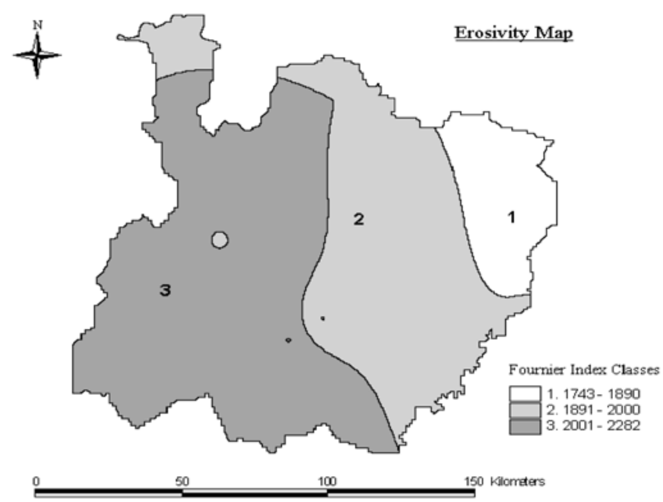


Figure 4.3: Rainfall erosivity map based on the reclassification of the linear extrapolation result

- *b) Socio-economic Indicators*

Socio-economic data collected in 1996 in all the settlements of the province were obtained from the regional services of planning and water resource management (Projet RESO, 1996-2000). The locations of the settlements were recorded by means of a GPS. A point-coverage was created and a Thiessen polygon interpolation was used to generate artificial boundaries for the villages. Different variables contained in the database were used to create the following GIS layers.

- *b.1Population density and grazing intensity maps*

According to a study of Gray and Kevane (2001), population increase in the study area has contributed to some extend to agricultural intensification. Nevertheless, it is strongly believed in the area that population pressure is one of the most important factors contributing to land degradation. A population density map was created using the area of the villages generated by the Thiessen interpolation and the population data. It was divided into four classes according to the criteria shown in Table 4.2.

- In addition, a grazing intensity map was created using the number of cattle (TLU) per village. Four classes were distinguished according to the criteria shown in Table 4.3

- *b.2 Manure availability:* The manure availability was estimated based on the number of cattle per household, derived from the equation:

$$N = \frac{d * C}{P} \qquad (4)$$

where d = 6, the mean number of persons per household (which is an aggregate estimate at provincial level derived from the 1996 national census); C = number of cattle per village (expressed in Tropical Livestock Units); P = village population (excluding urban areas). Five classes (Table 4.4) were used to create a map of the potential manure availability per village.

Table 4.2: Classification of population density

Classes	Population density (/km^2)	Consequences for villages	State and trend of land degradation
1	0-10	Low pressure on natural resources	Low degradation ↓
2	10-30	Medium pressure	
3	30-90	High pressure	
4	>90	Very high pressure on natural resources	High degradation

Table 4.3: Classification criteria for grazing intensity

Classes	Grazing intensity (TLU/ km^2)	Consequences for villages	State and trend of land degradation
1	0-10	Low pressure on natural resources	Low degradation ↓
2	10-50	Medium pressure	
3	50-100	High pressure	
4	>100	Very high pressure on natural resources	High degradation

Table 4.4: Classification criteria for manure availability

Classes	Number of cattle (TLU per household)	Consequences for villages	State and trend of land degradation
1	0	No fertilization capacity	High degradation
2	1-2	Very low capacity	
3	3-5	Medium capacity	
4	5-10	High fertilization capacity	
5	>10	Very high fertilization capacity	Low degradation

Table 4.5: Classification of the farming systems

Classes	Distance (km)	Consequences for villages	State and trend of land degradation
1	0-5	Relatively high capacity	Low degradation
2	5-10	Medium	
3	>10	Low capacity	High degradation

Table 4.6 Classification of land management capacity of the villages

Classes	Management activities	Consequences for villages	State and trend of land degradation
1	Yes	High degradation control capacity	Low degradation
2	No	Low degradation control capacity	High degradation

Table 4.7. Classification of fuel wood demand

Classes	Distance to the city (km)	Consequences for villages	State and trend of land degradation
1	0 –15	Very high deforestation	High degradation
2	15-30	High deforestation	
3	30-70	Medium deforestation	
4	> 70	Low deforestation	Low degradation

Table 4.8 Classification of the institutional capacity of the villages

Classes	**Classification criteria**	**State and trend of land degradation**
1	Tenure regime of native population	Low degradation
2	Tenure regime of neighbouring immigrants	
3	Tenure regime of immigrant pastoralists	
4	Tenure regime of immigrants from the central plateau	High degradation

Table 4.9 Classification of institutional capacity of the villages

Classes	**Classification criteria**	**State and trend of land degradation**
1	Presence of both project and NGO	Low degradation
2	Presence of one partner	
3	No partner in land management	High degradation

- *b.3 Farming system:* The complexity of farming system was represented by the possibility that farmers have to purchase farming inputs on the basis of the distance to markets. The villages that have a market were selected in the point coverage, and a distance map was created and classified as shown in Table 4.5

- *b.4 Capacity to adopt new technology:* The capacity of local communities to adopt new technology was measured according to the presence or lack of land management activities, such as water and erosion control and agricultural intensification activities in the villages. This was used to create a map according to the criteria as shown in the Table 4.6

- *b.5 Existence of water erosion:* The regional service water resources has assessed the importance of erosion in each village based on the following criteria: (1) presence of erosion: existence gullies and sedimentation manifested by untimely drying up of lakes and rivers; (2) low erosion: no visible physical aspects.

- *b.6 Deforestation due to fuel wood demand:* Because of the relatively high vegetation cover and rainfall in the province (compared to the rest of the country) and the relatively low rural population density, it was assumed that fuel wood consumption for rural households does not have a significant impact on deforestation (compared to the impact of urban consumption). Thus a fuel wood demand map was created (Figure 4.4), based on the scenario for supplying the city of Bobo-Dioulasso, using the following criteria (Table 4.7):

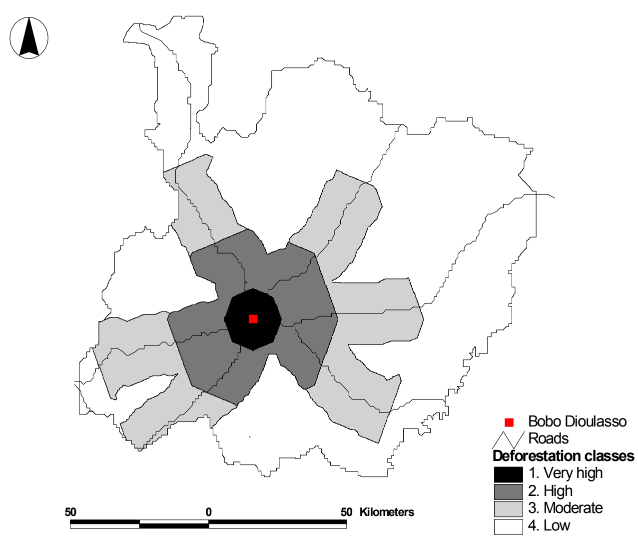


Figure 4.4. Fuel wood demand map at provincial level

1. Most villagers within a distance of 15 km around the city carry wood for sale in order to purchase their basic needs: industrial products, medicines, etc;

2. From 15 to 30 km the wood is carried to the city (in smaller quantities) by donkey-traction carts;

3. From 30 to 70 km along the main roads the wood is transported by trucks, mostly from participatory forestry exploitation areas;

4. The area outside a range of 70 km is not significantly affected (low profit from the wood exploitation because of high maintenance costs for the trucks).

- *b.7 Impact of immigration and traditional tenure system:* The information gathered from PRA showed that tenure is perceived as an important factor of land degradation, because of limited rights given to some groups of stakeholders to implement land management activities. The tenure system in the study area is based on the customary rights of the native ethnic group. Four main types of tenure systems were identified and used to create a map classified as follows (Table 4.8):
  - The system of the native population, which gives full possibilities for implementing land management activities;
  - The system of the immigrant cultivators from neighbouring ethnic groups, who in the longer term assimilate to the local population;
  - The system of the migrant pastoralists who exist with land insecurity;
  - The system applied to the immigrant Mossi coming from the central plateau of the country, who have fewer possibilities for managing the land. Because of the importance of immigration in the area and its impact on the increase of agricultural lands, this was considered by PRA respondents to be the most important tenure-related factor contributing to land degradation.

- *b.8 Institutional capacity:* This was determined according to the presence of development partners in the villages. The presence of institutions specialized in land management activities (agricultural projects and NGOs) was used to create a map according to the criteria listed in Table 4.9

- *4.2.4 Implementation of the expert system*

The expert system was implemented using an Expert System Shell developed by the ACE Division at ITC in ENVI software using IDL. The different evidence layers were created in a raster format using the GIS /ILWIS package.

4.2.4.1 Creating the expert rules

Assigning the *a priori* probability of occurrence for a piece of evidence is the most subjective aspect of an expert system (Forsyth, 1984 in Skidmore, 1989). In order to calculate the equation (1) for each hypothesis, we need to determine the *a priori* conditional probabilities $P(E_b|Ha)$. In some cases this can be derived statistically, but the probability may also be estimated from the expert knowledge. For instance, Skidmore (1989) used qualitative methods including expert-foresters' interviews, field observations and information compiled from the Forestry Commission of New South Wales in Australia to derive *a priori* probability matrices. These matrices served to build an expert system to classify eucalypt forest types at higher accuracy than the classical remote sensing classification techniques. In the present study, we used the knowledge of the local planners and their perceptions about land degradation regarding each piece of evidence, which were inferred from the PRA surveys. Three main classes were used for assessing the state of land degradation (low, moderate, high). Based on the trend of the degradation for each evidence layer as indicated in the different tables (Tables 2 to 8), we assigned a qualitative value (low, medium or high) to each evidence class in the different classes of land degradation (Table 4.10).

Table 4.10: Qualitative weighting matrix of evidence layers built by the farmers

Example of Evidence classes	**Land Degradation**		
	Low	**Moderate**	**High**
1 (Low)	**L**	**M**	**H**
2 (Moderate)	**M**	**H**	**M**
3 (High)	**H**	**M**	**L**

These qualitative values served as a basis for quantitative ranking between 0 and 10, representing the probability (as a measure of subjective belief) of each item of evidence occurring for each hypothesis for the considered $P(E_b|Ha)$. They were used to build the *a priori* conditional matrices, which were linked to the GIS evidence layers in the inference engine of the expert system.

4.2.4.2 Verification

The reliability of the expert system knowledge was verified based on participatory surveys conducted in the villages of the study area. In each sample village a discussion was conducted with the members of the local participatory planning committee, who are well trained by project for implementing participatory methods. To verify whether the system was built according to the perceptions of the local land users, in-depth discussions were organized in the different villages. This made it possible to:

- Determine how the indicators of land degradation conformed to their own views;
- Build a weight matrix for each variable that was subsequently transformed into a probability matrix as shown in Table 4.11.

Table 4.11 *A priori* probability matrices built in sample villages in the study area on the basis of interviews with farmers

Evidence Layers	classes	Land Degradation classes								
		k-Vigue			Toussiana			Somousso		
		L	M	H	L	M	H	L	M	H
Soil	**1**	.9	.6	.4	.8	.6	.4	.9	.6	.4
	2	.5	.7	.5	.5	.7	.5	.5	.7	.5
	3	.4	.5	.7	.4	.5	.7	.4	.5	.7
Slope	**1**	.8	.6	.3	.8	.6	.3	.8	.6	.3
	2	.6	.7	.5	.5	.7	.6	.6	.7	.5
	3	.3	.5	.7	.2	.5	.9	.3	.5	.7
Vegetation	**1**	.8	.5	.3	.9	.5	.3	.8	.5	.3
	2	.5	.7	.6	.5	.7	.6	.5	.7	.5
	3	.4	.6	.7	.2	.6	.7	.4	.6	.7
Farming system	**1**	.9	.6	.4	.7	.5	.4	.9	.6	.4
	2	.5	.7	.4	.5	.6	.6	.5	.7	.4
	3	.3	.5	.8	.5	.6	.7	.3	.5	.8
Grazing intensity	**1**	.8	.6	.3	.8	.6	.3	.8	.6	.3
	2	.7	.6	.3	.8	.6	.3	.7	.6	.3
	3	.5	.7	.6	.6	.7	.5	.5	.7	.6
	4	.3	.5	.7	.4	.6	.7	.3	.5	.7
Population pressure	**1**	.9	.6	.4	.9	.7	.3	.9	.6	.4
	2	.6	.7	.6	.7	.5	.5	.6	.7	.6
	3	.2	.5	.7	.5	.7	.8	.3	.5	.7
	4	.2	.5	.7	.3	.7	.8	.3	.5	.8
Fuel wood demand	**1**	.3	.6	.8	.3	.4	.7	.3	.5	.7
	2	.5	.6	.8	.3	.5	.4	.4	.6	.5
	3	.6	.7	.5	.5	.6	.5	.5	.6	.5
	4	.9	.7	.3	.7	.6	.4	.7	.5	.4
Tenure regimes	**1**	.7	.6	.5	.7	.5	.4	.7	.6	.4
	2	.7	.6	.5	.7	.5	.4	.7	.6	.4
	3	.5	.7	.5	.5	.7	.5	.6	.7	.6
	4	.3	.7	.4	.3	.5	.6	.4	.5	.7
Migration	**1**	.7	.5	.4	.7	.6	.4	.7	.5	.4
	2	.7	.5	.4	.7	.6	.4	.7	.5	.4
	3	.5	.6	.5	.5	.5	.5	.5	.5	.5
	4	.4	.6	.7	.4	.6	.7	.4	.6	.7
Organic fertilizing	**1**	.2	.6	.9	.3	.6	.9	.2	.6	.9
	2	.3	.5	.7	.5	.6	.7	.3	.4	.6
	3	.5	.7	.5	.6	.7	.6	.5	.7	.6
	4	.8	.6	.4	.8	.7	.5	.8	.6	.4
	5	.9	.5	.2	.9	.7	.4	.9	.5	.2
Institutional capacity	**1**	.8	.6	.4	.8	.6	.5	.8	.6	.4
	2	.5	.7	.5	.6	.7	.6	.5	.7	.5
	3	.4	.6	.7	.3	.6	.9	.4	.6	.7
Participatory land management	**1**	.3	.5	.8	.4	.6	.9	.3	.5	.8
	2	.7	.5	.2	.8	.6	.3	.7	.5	.2
Rainfall erosivity	**1**	.7	.6	.3	.7	.5	.4	.7	.5	.4
	2	.6	.7	.5	.6	.7	.6	.6	.7	.6
	3	.3	.5	.7	.3	.5	7	.3	.5	.7
Perception of erosion	**1**	.4	.6	.7	.3	.6	.7	.3	.6	.8
	2	.8	.5	.4	.8	.6.	.3	.8	.5	.2

Table 4.11 *A priori* probability matrices built in sample villages in the study area on the basis of interviews with farmers

Evidence Layers	Classes	Bekuy L	Bekuy M	Bekuy H	Kadomba L	Kadomba M	Kadomba H	Samandeni L	Samandeni M	Samandeni H
Soil	**1**	.8	.5	.3	.8	.5	.3	.9	.6	.4
	2	.6	.7	.6	.6	.7	.6	.5	.7	.6
	3	.4	.5	.7	.4	.5	.8	.3	.5	.8
Slope	**1**	.8	.6	.4	.8	.5	.3	.7	.5	.2
	2	.6	.7	.6	.6	.7	.6	.5	.7	.5
	3	.3	.5	.8	.4	.5	.8	.3	.5	.8
Vegetation	**1**	.8	.6	.3	.8	.6	.3	.8	.5	.3
	2	.6	.7	.5	.6	.7	.6	.5	.7	.6
	3	.3	.6	.7	.4	.6	.7	.2	.5	.8
Farming system	**1**	.9	.6	.3	.9	.6	.3	.8	.5	.3
	2	.6	.7	.5	.6	.7	.5	.5	.7	.6
	3	.4	.6	.8	.2	.6	.8	.2	.5	.8
Grazing intensity	**1**	.8	.6	.3	.8	.6	.3	.8	.6	.3
	2	.6	.7	.6	.7	.5	.4	.7	.6	.3
	3	.4	.6	.7	.5	.7	.6	.5	.7	.6
	4	.2	.5	.9	.2	.5	.9	.3	.5	.9
Population pressure	**1**	.8	.6	.3	.8	.6	.2	.9	.6	.3
	2	.6	.7	.6	.6	.7	.6	.7	.6	.5
	3	.5	.6	.5	.5	.7	.7	.5	.7	.6
	4	.3	.5	.9	.3	.5	.7	.3	.5	.9
Fuel wood demand	**1**	.3	.6	.9	.3	.5	.8	.3	.5	.7
	2	.5	.7	.5	.5	.6	.6	.5	.6	.5
	3	.7	.7	.6	.6	.7	.6	.5	.6	.5
	4	.8	.7	.3	.7	.5	.3	.7	.5	.4
Tenure regimes	**1**	.7	.5	.4	.7	.5	.4	.7	.5	.4
	2	.7	.5	.4	.7	.5	.4	.7	.5	.4
	3	.5	.6	.5	.5	.7	.6	.5	.6	.5
	4	.4	.6	.7	.4	.6	.7	.4	.6	.7
Migration	**1**	.8	.7	.5	.8	.5	.3	.8	.6	.3
	2	.8	.7	.5	.8	.5	.3	.8	.6	.3
	3	.5	.7	.5	.5	.7	.5	.5	.7	.5
	4	.4	.5	.7	.3	.5	.7	.4	.6	.7
Organic fertilizing	**1**	.2	.6	.9	.3	.6	.9	.3	.6	.9
	2	.5	.7	.6	.5	.7	.6	.3	.7	.7
	3	.5	.7	.5	.6	.7	.6	.5	.7	.5
	4	.7	.6	.5	.7	.5	.4	.7	.7	.3
	5	.9	.6	.2	.8	.5	.2	.9	.5	.2
Institutional capacity	**1**	.7	.6	.3	.7	.6	.3	.8	.6	.3
	2	.5	.6	.5	.5	.6	.5	.5	.6	.5
	3	.3	.5	.7	.4	.5	.7	.3	.5	.7
Participatory land management	**1**	.3	.5	.7	.3	.5	.7	.3	.5	.8
	2	.8	.6	.3	.8	.6	.3	.7	.5	.3
Rainfall erosivity	**1**	.8	.6	.3	.8	.6	.3	.7	.6	.4
	2	.5	.7	.5	.5	.7	.5	.6	.7	.5
	3	.3	.6	.7	.2	.6	.7	.4	.5	.7
Perception of erosion	**1**	.4	.6	.7	.3	.6	.7	.4	.5	.7
	2	.9	.6	.3	.8	.6	.3	.8	.5	.4

Column groups: Land Degradation classes (Bekuy, Kadomba, Samandeni).

The classification of the evidence layers is based on Table 4.2 to Table 4.9

4.2.4.3 Validation of the Expert System

The accuracy of the expert system was tested using field data collected in an independent sample set of 50 villages randomly selected in the study area. For this purpose, a participatory mapping was conducted in the 50 villages. The members of the participatory planning committee in each village assigned an overall weight for each indicator of land degradation used to build the expert system as follows: 1 for low, 2 for moderate, and 3 for high degradation. A participatory sample map was created, showing the overall land degradation class for each sample village (represented by the mean weight of all the indicators). In the regional spatial database, villages are represented as polygons with (simulated artificial) boundaries created by Thiessen polygon interpolation. The map produced by the expert system was evaluated against this participatory map used as ground truth data (n = 50 villages), to check the accuracy of the expert system. We determined the overall mapping accuracy (calculated at 95% confidence interval) representing the ratio of the number of correctly mapped sample cells over the total number of cells sampled in an error matrix (Richards, 1993; Skidmore et al., 1996). The evidence layers used for building the expert system were also used to create a GIS map by an overlay operation and the final result was reclassified in three main categories (low, medium and high). The accuracy of this GIS overlay was also tested using the same data collected from the participatory planning committees.

4.2.4.4 Spatial analysis of land degradation using the expert system for a regional perspective

Perceptions may vary between the villages, resulting in important differences in the (local) probability matrices and potentially causing important errors in the estimates of land degradation by the expert system in many places. We therefore checked whether there were significant differences between the *a priori* conditional probability matrices constructed in the different villages using the Kruskal-Wallis test. The null hypothesis was that the medians of the evidence class probabilities (μ_i) were equal for all the sample villages {i = 1, .., 6}, and the alternative hypothesis was that these medians were different for some sample villages. Finally, in order to understand the impact of each physical or socio-economic parameter on the global land degradation assessment by the expert system, a spatial analysis was performed by overlaying each individual evidence layer with the expert system map.

4.3 Results

A visual comparison of the land degradation maps in Figure 4.5 shows some differences between the results of the conventional GIS map and the map produced by the expert system. For instance, the GIS map shows that the high degradation areas are located at the north and eastern sides of the province, while the central to western sides have lower degradation. On the other hand, the expert systems shows that the high degradation occurs more in the western sector, while the northeastern parts of the province are less degraded.

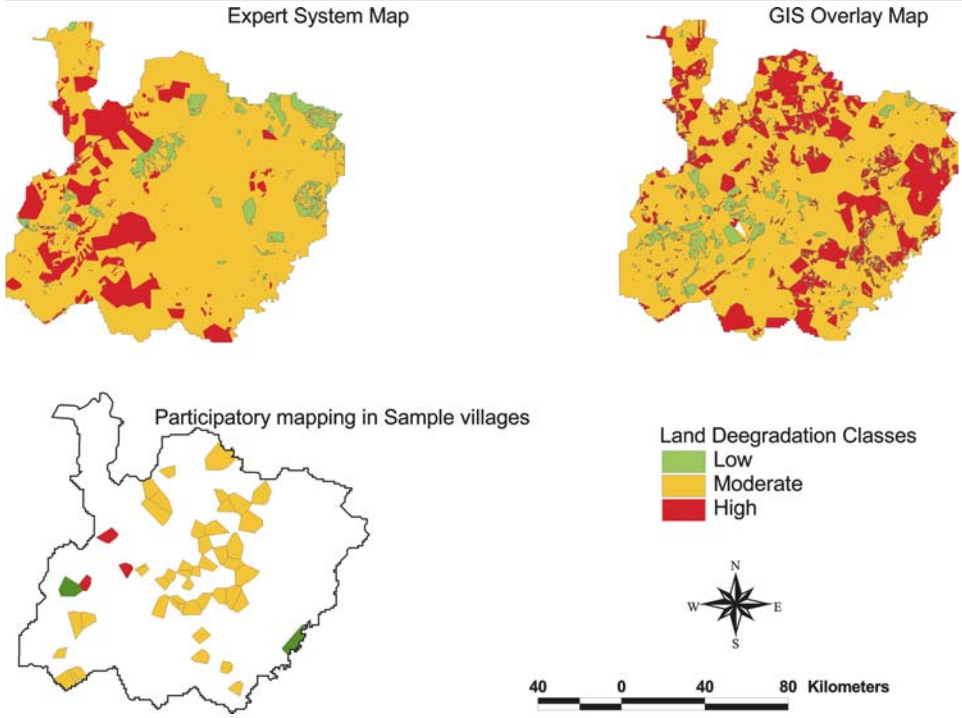


Figure 4.5 Land degradation maps Produced by conventional GIS and the expert system

The confusion matrices (Tables 4.12a and 4.12 b) were calculated for both the expert system and the conventional GIS overlay technique. These results show that for both methods a very high proportion of pixels classified as *low land degradation* by the farmers were misclassified as *moderate land degradation*.

Table 4.12a. Confusion matrix of the expert system land degradation map

Expert system MAP	**Sample Villages (Number of Pixels)**			Total
	low	med	high	
low	311	539	94	944
mod.	3628	48558	2702	54888
high	24	4517	918	5459
Total	3963	53614	3714	61291

Overall accuracy = 81%. Villages are considered as polygons not as points

Table 4.12b Confusion matrix of GIS overlay map

GIS MAP	**Sample Villages (Number of Pixels)**			Total
	low	med	high	
low	11	1392	27	1430
mod	3202	36231	2221	41654
high	450	16841	916	18207
Total	3663	52885	3164	61291

Overall accuracy = 60% Villages are considered as polygons not as points

However, this proportion is lower for the expert system (57%) than for the conventional GIS (97%). Both methods classified the pixels belonging to the class *moderate land degradation* with good accuracy (88% for the expert system and 86% for the conventional GIS). For the class of *high land degradation*, the proportion of pixels misclassified as *moderate land degradation* is also very high for both methods (82% for the expert system and 92% for the conventional GIS). The overall mapping accuracy given by the confusion matrices was nearly 82% for the expert system while the accuracy of the GIS map was 60%.

The result of the non-parametric Kruskal-Wallis test showed that there was no significant difference between the *a priori* conditional probability matrices constructed in the different villages (p value > 0.05). This means that the medians of the evidence class probabilities (μ_i) were equal for all the sample villages {i = 1, .., 6}. Therefore we can conclude that the local perceptions and *a priori* knowledge used to construct the probability matrices do not vary significantly form one location to another.

The spatial analysis of the expert system map shows that the distribution of the different classes of land degradation in the study area is respectively 5% for low degradation, 80% for moderate degradation and 15% for high degradation. In the participatory mapping based on the farmers' perception in the 50 sample villages (randomly selected), nearly 90 percent of villages were also classified as *moderate land degradation* areas. The results of the spatial analysis based on overlaying the expert system map with the individual evidence layers are summarized in Table 4.13 and Table 4.14. The most significant results concern the variables such as the tenure regimes, participatory land management, population density and cattle density. According to the results in Table 4.13, the tenure regime of the native population coincides entirely with the areas classified as *low land degradation* (5% of the total province), while native and immigrant tenure regimes share equally the areas classified as *high land degradation* (7% of the total province each). This is far more than the tenure regime pastoralists with only 1%. The results show also that the areas perceived as *low degradation* areas correspond exactly to places where participatory land management activities are being implemented while *high land degradation* is found where no participatory land management activities are implemented.

Table 4.13. Spatial distribution of the classes of tenure regimes and land management in the different categories of land degradation (%)

Land degradation	Tenure Regimes			Land management	
	Native farmers	Immigrants	Pastoralists	No activity	Existing activities
Low	5	-	-	-	5
Mod	40	36	4	34	47
High	7	7	1	13	1

As shown in Table 4.14, places perceived as *low land degradation* areas are found in moderate to low population and regions where cattle density is also relatively low (less than 50/ km^2). However, a great proportion of *high land degradation* areas also coincide with the low-density areas.

Table 4.14. Spatial distribution of the classes of human and cattle population in the different categories of land degradation

Land Degradation	Population Density (/km^2)				Cattle Density classes			
	< 20	20 - 50	50 - 80	> 80	<10	10 - 50	50 - 100	> 100
Low	4	1			2	2	1	-
Mod	39	25	8	8	32	41	5	3
High	7	5	-	3	2	12	-	-

4.5 Discussion

4.5.1 Technical aspects of the expert system

As attested by (Bajte, 1996), the study shows that the results of global models of land degradation assessment are difficult to evaluate. For the present case, the results obtained by both methods could have been negatively influenced by many factors. For instance it could be mentioned the possible shortcomings underlying the construction of the expert system and the uncertainties associated with the data used to create the GIS layers. Assigning the quantitative values for the *a priori* probabilities was also a difficult task in building the expert system, as it strongly depends on expert judgment. The principle of using the qualitative ranks, which was quite easily managed by the local farmers, was the simplest way to overcome this problem. Each qualitative rank (low, medium or high) allowed grouping the probabilities within classes in which the quantitative values were chosen. The uncertainties associated with the participatory mapping procedure (possible wrong judgement by the local farmers resulting in wrong assessment of the status of land degradation in some villages) may also affect the final results of the evaluation.

Nevertheless, the overall mapping accuracy of the expert system was (in absolute values) higher then the conventional GIS map of land degradation. Two-fold explanation may be given. Firstly, the classes of the evidence layers are crisp and the overlay operation in GIS is likely to generate categorical decision-boundaries that have an important impact on the final map. In contrast, the expert rules introduce more gradual variations between the different evidence classes by assigning the probability rules that generate more continuous decision-boundaries. Secondly, some degradation variables may not be appropriate. Therefore, the weights assigned to the evidence classes by the expert rules make it possible to discriminate these inappropriate layers or to find different alternatives by navigating through the decision tree. The GIS overlay operation does not allow for such a procedure.

The result of the accuracy assessment suggests that the expert system for mapping land degradation based on farmers' perceptions gives in general a pessimistic view of what is *low land degradation*. The tendency is to perceive *low land degradation* as *moderate land degradation,* which explains an important misclassification of pixels from *low* to *moderate* land degradation. On the other hand, the farmers' perceptions as reflected by the expert system give a more optimistic view by reclassifying *high* into *moderate* land degradation. In any case we can conclude based on the overall mapping accuracy, that the expert system was fairly similar to the participatory assessment representing the farmers' perception on land degradation.

An important issue raised during the construction of the expert system was to avoid aggregation bias that could be introduced by the differences of the probability matrices. The question was whether the method introduced generalization errors in the knowledge base since the procedure may not consider the variability in local knowledge. However, there was no significant difference between how the villagers in the different locations rank the evidence classes. This means that using any of these matrices will not induce significant errors in the final land degradation map regarding the perception of the local people in the other villages. Finally Bayes' theorem is fairly robust with respect to handling such issues, together with other problems such as the "conditional independence" of the evidence (Skidmore, 1991; Naylor, 1989).

Other methods may be used in attempting to improve the quality of the knowledge base and hence the results of the expert system. For instance as suggested in Skidmore et al. (1991), increasing the number of sample villages could contribute to improve the result of the accuracy assessment. If necessary, we could also use a sampling method based on stratification criteria to create rules for (relatively) homogeneous areas based on biophysical, socio-cultural or economic factors (e.g. micro ecological zones, tenure regimes, intensification level, etc). These stratified units could be stored in a GIS layer, used to update the set of probability matrices on iterating with the x_i, y_i locations in the GIS. However, as argued in Newton et al. (1987), more accurate estimation, inference and calculation of uncertainty may not necessarily lead to more accurate results for an expert system.

4.5.2 The expert system supporting the bottom-up land use planning

The good results obtained by the expert system in assessing land degradation based on the perceptions of the local farmers suggest that it could be reliably used to support bottom-up land planning processes. The qualitative assessment gives a global (coarse) estimation of the state of land degradation that can serve as a regional decision support tool; for instance to determine high or low priority intervention areas.

The results of the spatial analysis in Table 5.14 suggest that the tenure regimes have an important impact on land degradation. In particular, the absence of immigrants is associated with low degradation. However, there is no evidence that their presence at a high proportional level is *de facto* associated with *high land degradation*, because they share the size of degraded areas equally with the native population. This confirms also the findings of Gray (1999) in the same area, that there was no significant difference in the agricultural practices between the Mossi farmers and the natives and, therefore, no evidence that they contribute more to degradation. On the other hand, this result contradicts the strong opinion among agriculturalists that associates the presence of pastoralists with severe land degradation. The low degraded lands are located in areas that have participatory land management activities, whereas the majority of highly degraded lands are found where these activities have not yet been implemented. These results give hope to regional planners that a widespread implementation of land management activities based on the approach *Gestion des Terroirs* (Capo-Chichi et al., 1995; UNSO, 1994) will make a significant global contribution to combating land degradation at a regional scale.

The analysis of the population factor shows that *low degradation* areas are associated with low population density. The reason could be that low-density areas correspond in general to new immigration zones or remote villages with poor road accessibility that still have substantial resources. On the other hand, the results suggest that there is no evidence of high population density contributing *de facto* to high degradation. The reason may be that, by excluding the semi-urban areas (district towns), the high-density areas correspond with the irrigated areas that have higher ecological and socio-economic potentials (water, vegetation, extension services) and better organisational frameworks (co-operative systems). Another important reason may be that the population pressure leads to scarcer resources thereby simulating competition between users, which improves land management through agricultural intensification (Boserup, 1965; Gray, 1999; Gray and Kevane, 2001). Similar observations can be noted for cattle density. However, the fact that the most highly degraded lands are found in the (relatively) low cattle density areas (less than 50 TLU/km^2) shows that the lack of manure contributes significantly to degradation. On the other hand, the low cattle density means less pressure on the vegetation, and hence low degradation.

The study shows that the participatory procedure of building the knowledge base can also be used to support and enhance the results of local planning processes. For example, the ranking procedure made it possible to cross check the validity of the information collected with local farmers with respect to their previous diagnosis using PRA methods. By assigning quantitative values to the evidence classes, it becomes easy to identify the parameters that contribute most to land degradation. For instance, in some places soil acidity (manifested by the presence of some herb species such as *Striga* in the fields) was included in the set of variables of land degradation, and was allocated a more important weight than other factors such as soil erosion. This information helped the regional staff of the PNGT programme to understand the reasons for the failure of the initial soil erosion and water control project implemented in these villages.

4.6 Conclusion

The expert system was built to map land degradation at regional level, using local knowledge and local land management planning data, as a means of supporting bottom-up planning procedures. The expert system successfully integrated biophysical, socio-economic and even cultural factors, using the knowledge extracted from PRA methods. The variables representing the main indicators of land degradation were used to create the GIS layers, which were combined in a rule base using Bayesian probability rules. The validation of the expert system using participatory mapping data gave a good overall accuracy. It was shown that the expert system had a higher mapping accuracy compared to a conventional GIS mapping. The procedure of validation in a participatory context reinforced farmers' awareness of a global process of land degradation and their understanding of the different factors contributing to degradation. By connecting the biophysical factors to the socio-economic explanations and local perceptions of the land degradation processes, the procedure serves as a bridge between the coarse scale investigation methods (i.e. using remote sensing) and the local situations. By using the perceptions and knowledge of the local people to forecast the state of land degradation at regional level, regional decision-makers are brought closer to the local needs. This should contribute to stimulate policy interventions that better reflect the objectives of participatory land use planning and land management.

CHAPTER V∗

EXPLORING SUSTAINABILITY OF LAND MANAGEMENT SYSTEMS IN BOTTOM-UP LAND USE PLANNING

∗ This chapter is based on L. G. Sedogo, A. K. Skidmore, S.M.E. Groten *(submitted*) Exploring the sustainability of land management systems in bottom-up land use planning. *Land Degradation and Development*

Abstract

In Burkina Faso, land degradation has prompted a variety of interventions and environmental policies, ranging from draconian applications of top-down measures to the implementation of participatory land management activities based on the approach Gestion des Terroirs. In the context of participatory land use planning, the study presents an expert system that predicts land degradation as a means of assessing the sustainability of local land management systems at regional level. Different sources of evidence derived from physical and socio-economic parameters were inferred from land degradation diagnoses made from PRA (participatory rural appraisal) surveys of different villages. The evidence layers were created and stored in the spatial database of a GIS. By combining the evidence layers with probability rules (derived from local knowledge), the expert system predicted land degradation with good accuracy when compared with participatory mapping data (used as ground truth). Two other technical methods for measuring land quality indicators were also used to assess the sustainability of village land management systems: a nutrient budget model and a vegetation change trend map created using a NOAA NDVI satellite imagery time series. A comparison of these three methods showed the relatively better agreement of the expert system with the PRA assessment method. The objectives set up by the local farmers for their participatory land use plans were used as a basis to perform a scenario analysis predicting different status for land degradation.

5.1 Introduction

In Burkina Faso, government institutions present populist environmental narrative that natural resources face a catastrophic trend of degradation. In particular, land degradation is considered one of the main causes of a quasi-endemic food insecurity, unsustainable economic growth and important wildlife depletion. This has prompted a variety of interventions and environmental policies, ranging from draconian applications of top-down measures to the implementation of participatory land management activities based on the approach Gestion des Terroirs*6* (UNSO, 1994; Lompo et al., 2000). Even without the evidence of processes and clear directions of change, government and donor organizations have widely implemented environmental management programmes that alter how resources are allocated, controlled and managed. Different methods and models have been created for the purpose of measuring the state of degradation. However, they have not yet contributed enough to stimulate adequate measures for tackling the problem (Shaxson et al., 1995; Mazzucato and Niemeijer, 2000). The dynamic of the local socio-cultural and economic systems emphasize the need to understand the implications of the land management activities, beyond the participatory planning horizon. However, the link between the social and environmental systems regarding environmental risk is hardly considered by most conventional approaches (Pretty, 1998; Woodhill and Röling, 1998).

Most models proposed for predicting the rate of soil degradation at various scales (Wischmeier and Smith, 1978; CEC, 1992; Millward and Mersey, 1999) do not integrate the perceptions of the end users (Chokor and Odermo, 1994; Dejene, 1997). On the other hand, the set of indicators of land quality (LQIs), developed as a means to better coordinate actions on land-related issues, such as land degradation, include vegetation cover and nutrient balance (Hurni, 1996; Dumanski, 1997). The decline in vegetation cover is acknowledged as a major factor contributing to water erosion in the world (Batjes, 1996). The NOAA AVHRR satellite system has been successfully used to monitor the state of vegetation cover at different scales in various applications (Tappan et al., 1992; Lobo, 1995; Gitelson et al., 1998; Rasmussen, 1998; Groten et al., 1999; Genovese et al., 2001). Nutrient balance and nutrient budget models have also been proposed to assess the state of agricultural systems at different scales (Stoorvogel and Smaling, 1990; Brower et al., 1993; Stoorvogel et al., 1993; Prudencio, 1993; Budelman et al., 1995; Krogh, 1995; Scoones and Toulmin, 1998; Harris, 1998).

Most quantitative models used for land degradation investigations in Africa portray negative environmental figures at the continental scale, and particularly for the Sahelian countries (Smaling et al., 1996; UNEP, 1997; Bridges and Oldeman, 1999). However, this

6 The *Gestion de Terroirs* approach has developed over recent years in Sahelian West Africa as a means of addressing environmental degradation problems through participatory land management activities. Such problems include: loss of soils through water and wind erosion; declining soil fertility; a loss of vegetative cover an increasing vulnerability to drought; and a general reduction in the diversity of plant and animal life (UNSO, 1994).

opinion is increasingly challenged by studies questioning the actual occurrence of land degradation in areas where it has been presumed to be widespread (Howorth and O'Keefe, 1999; Mazzucato and Niemeijer, 2000). Questions have also been raised about the real impact of the presumed causes, such as the expansion of agriculture due to population pressure (Mazzucato and Niemeijer, 2001) and the concordance between the results of coarse-scale assessment methods based on remote sensing techniques and local assessment based on farmers' perceptions and field investigations (Gray, 1999). To design sustainable land management strategies, it is essential to determine the symptoms and causes of land degradation from both modern and traditional knowledge (Lambin, 1993; Martin and Lockie (1993) in Lindskog and Tenberg, 1994). Therefore, methods for integrating the local and socially constructed farmers' perceptions of land degradation are needed.

GIS can integrate different variables from multiple sources in order to assess land degradation at different scales (Grunblatt et al., 1992; Mellerowicz et al., 1994; Desmet and Govers, 1996; UNEP, 1997). However, there are many obstacles to integrating local and scientific knowledge for assessing land degradation, to support sustainable participatory land use decision-making using GIS (Scoones and Thompson, 1994; Sedogo and Groten, 2000). In particular, it has been difficult to integrate expert knowledge (i.e. from local people) with GIS (Skidmore et al., 1997). Expert systems have proved to be more successful for integrating cognitive and scientific knowledge (Balachandran, 1995).

In the present study, the results of a Bayesian expert system mapping land degradation at a regional scale are compared with the outputs of two other land degradation models using GIS and remote sensing (a nutrient balance model and a model mapping trends in vegetation dynamics using NOAA NDVI data). The *Gestion des Terroirs* approach has the multiple objectives of improving the livelihood of rural people while preserving the ecological potential of the resource base. By developing different scenarios corresponding to activities aiming to achieve these objectives, we should be able to forecast their potential impact on land degradation. The study predicts the potential impact of the land management activities that should allow achieving the main objectives of the local participatory land use plans: (1) increasing the agricultural production (2) increasing the household revenues (3) improving the social welfare (4) improving environmental conservation.

5.2 Methods and Materials

5.2. 1 Mapping trends in vegetation changes

In the study area, it is believed that the social, economic and technologic changes (high population growth and immigration, market orientation of rural economy, mechanization of agricultural production) result in pressure on the natural resources and contribute to land degradation. Vegetation change has been mapped using NOAA-NDVI data (downloaded from the website of Africa Data Dissemination Service (ADDS) (*http://edcintl.cr.usgs.gov/adds*). Even though the pixel size of 7.6 km often covers more than one village territory, the system was preferred to the 1 km NOAA NDVI data system because of its consistency in radiometric and temporal properties. The time series spanning the period between 1990 and 1999 was imported to the WINDISP software and clipped to the window corresponding to the coordinates of the study area. The images corresponding to the maximum NDVI for each year were extracted and converted into GIS coverages in Arc/Info. After transformation into a UTM coordinate system, they were overlaid with the village polygon map of the study area, to attach the maximum NDVI value of each year as an attribute to each village. The trend of NDVI against time was determined by regression analysis (Groten, 1990; 1999).

5.2.2 The nutrient budget model

The nutrient budget model used in this study is similar to the model proposed by Groten and Bogere (2001). It assesses the capacity of the local communities to maintain a sustainable level of productivity in their villages. The rational behind this method is based on the following assumptions:

(1) Agricultural research in Burkina Faso recommend the farmers to use a certain quantity of fertilizers in order to obtain an optimal productivity per hectare for the different crops.
(2) Productivity can only be sustained if the farmers are able to obtain the necessary quantities of chemical fertilizers (mainly from their agricultural revenues) and manure (from their livestock production).

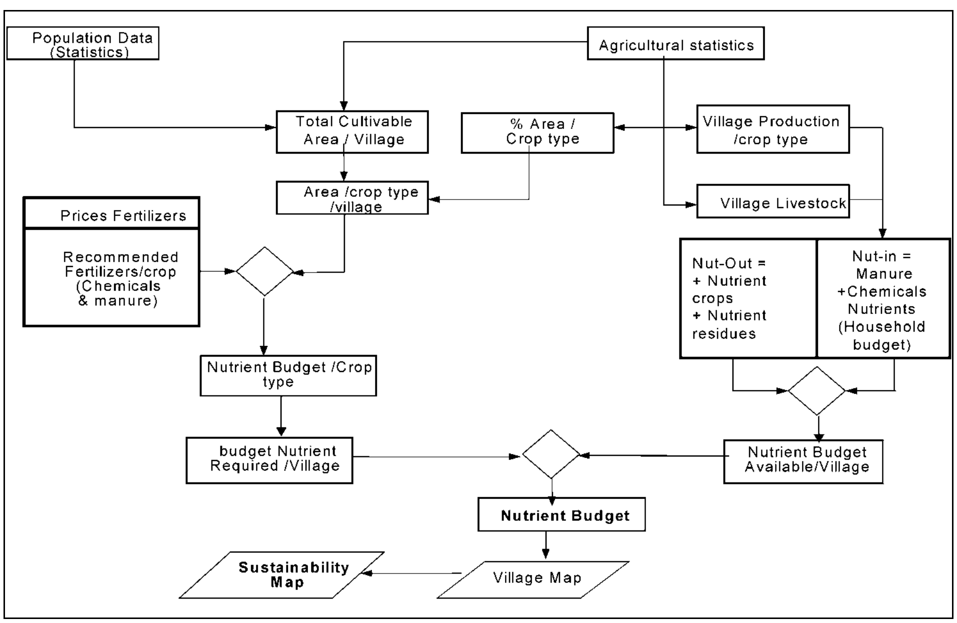


Figure 5.1: Flow chart of the nutrient balance model (adapted from Groten and Bogere, 2001; V. D. Bosch et al., 1998)

The method (detailed in figure 5.1) consists of determining the budget of the nutrients required and the nutrient budget potentially available in order to compute their ratio as follows:
The capacity of each village to maintain a sustainable level of productivity is determined by the equation (1):

$$Nut\_bud = \frac{Bud\_av}{Bud\_req} \qquad (1)$$

where: Bud_req is the nutrient budget required (for the cultivation of the different crops in each village) as recommended by the technical services;

- Bud_av is the nutrient budget potentially available in each village;
- Nut _bud is a ratio index, assessing the capacity of each village to maintain a sustainable level of productivity.

The nutrient budget required (Bud_req) was determined using equation (2). The inputs requirements (recommended by the technical services) per hectare for the main crops are given in the Table 5.1

Table 5.1 Quantities of fertilizers per hectare recommended and their official prices

	Cotton complex (kg/ha) (Price = 235 F/kg)	Urea (kg/ha) (Price = 224 F/kg)	Organic fertilizer (t/ha/2 years)
Cotton	300	150	
Maize	90	75	5 T /ha/ 2 years
Sorghum/millet	75	50	

$$Bud\_req = Bud\_chem + Bud\_org \qquad (2)$$

- Where:Bud_chem is the budget necessary for the purchase of the recommended quantity of chemical fertilizers, calculated based on the official prices in the province.
- Bud_org is the budget corresponding to a monetary value of the organic fertilizers, computed on the basis of the elements given in Tables 5.1 and Table 5.2

Table 5.2: Mean mass nutrient fractions (g kg^{-1}) of various resources used for the model

	Materials	N	P	K
Fertilizers	Cotton complex	14	9.6	10
	Urea	46		
	Cereal complex	15	6.5	12.5
	Manure	1.08	0.17	1.52
Harvest products	Cotton	2.4	0.29	0.65
	Maize	1.37	0.22	0.21
	Sorghum	17	0.2	0.31
	Millet	2.37	0.28	0.85
Crop residues	Cotton	1.35	0.07	1.2
	Maize	1.19	0.15	1.87
	Sorghum	0.83	0.05	4.6
	Millet	2.13	0.21	4.6

Source: Stoorvogel and Smaling (1990), Smaling (1998)

- To calculate Bud_chem and Bud_org, we determined the size of the total agricultural areas and the areas per crop type for each village using the agricultural statistics of the study area (collected every year by the Service of Agricultural statistics). To determine the nutrient budget potentially available per village (Bud_av), we used an input / output flow model adapted from Smaling (1993), Smaling (1998) for the study area. The variables involved in the computation of Bud_av are given in the equation (3).

$$Bud\_av = (IN1 + N2 - OUT1) \tag{3}$$

where

- IN1 = Households budget potentially available for purchasing chemical fertilizers. IN1 = [Prices of crop produced -(cost of food consumption + pesticides costs)]. The quantities of crops produced and the food consumption per village were determined using the agricultural statistics and the population data of the study area. The total costs were calculated using the official prices of crop products in the province
- IN2 = Monetary value of the nutrients contained in the organic fertilizers (manure) potentially available per village, based on the number of livestock. The use of monetary values allows normalizing the different elements of the equation (1) in the same units. Based on different studies in Burkina Faso (Dugue, 1989; Maatman, 2000) and Mali (Camara, 1996), we used a potential production of 1500 kg of manure per TLU per year (of which it was estimated that an average 50% is effectively used for fertilization) to determine the quantity of organic fertilizers. The quantity of manure potentially available per village was converted into quantities of the nutrient components namely nitrogen (N), phosphorus (P) and potassium (K), based on Table 5.2. The price of each nutrient was determined based on the mineral composition of the chemical fertilizers given in Table 5.2 and their official prices (given in Table 5.1 in local currency in CFA Francs)
- OUT1= Monetary value of the nutrients contained in crops harvests and crop residues. The costs of some elements in equation (2) (crop harvest products and crop residues) were also determined on the basis of their nutrient composition (N, P, K) given in Table 5.2 and the costs of the different nutrients (N, P, K).

5.2.3 The expert system

An expert system codes facts and relationships as set of heuristic (Lein, 1992). The expert system used in this study is a Bayesian implementation developed in the previous chapter based on an expert shell. The basis of the algorithm is that the likelihood of a hypothesis occurring given a piece of evidence, may be thought as a conditional probability. The research question to be answered by the expert system was: “Given land degradation classes existing in the province, what degradation type occurs at a certain location “X Y”. The sources of evidence are data derived from physical and socio-economic parameters, which were inferred from land degradation diagnoses based on PRA surveys in different villages engaged in designing local land management plans. The evidence layers were created and stored in the spatial database of the GIS. The heuristic knowledge related local constraints and perceptions to land degradation, based on the experience of the villagers (from simple narrative to real facts). It involved building a rule base, which in the present case was derived from PRA ranking methods that are largely used in participatory planning. The rule base represented a set of ranking matrices, which were treated similarly to probability matrices by reformulating the Bayesian equation into:

$$W(H_a \mid E_b) = \frac{W(E_b \mid H_a)W(H_a)}{W(E_b)} \qquad (4)$$

where:

- $W(H_a|E_b)$ is the degree of confidence (of the expert) in the rule that hypothesis H_a will occur, given a piece of evidence (E_b).
- $W(E_b|H_a)$ is the degree of confidence (of the expert) that there a piece of evidence E_b (e.g. steep slope), given the hypothesis (H_a) that land degradation class (a) (e.g., low) occurs at a certain location.
- $W(H_a)$ is the degree of confidence in the hypothesis that land degradation class (a) occurs at the given location, which is obtained from the PRA surveys.
- $W(E_b)$ is the degree of confidence in evidence alone, or the degree of confidence that any cell has an item of evidence (E_b) such as "low vegetation cover".

By analogue the ranking rules can be transformed into probability rules, where the expert system uses a Bayes' theorem formula to update $P(E_b)$, which is the probability of the evidence, for every evidence layer b=1,…,p; (Skidmore 1989).

$$P(E_b) = \sum_{a=1}^{n} P(E_b \mid H_a)P(H_a) \qquad (5)$$

The inference engine is the rule interpreter that controls and directs the flow of reasoning by examining rules and executing those that match the facts fetched from the fact base. The evidence layers as identified and classified in the previous chapter included GIS layers derived the following variables:

- Physical variables: soil, rainfall erosivity, slope, vegetation cover density;
- Socio-economic variables: population density, grazing intensity, manure availability, farming system, local coping capacity, fuel wood demand, local institutional capacity.

5.2.4 Comparing the different methods for regional land degradation assessment

The expert system was tested and validated using ground truth data representing the results of participatory land degradation mapping based on farmers' perceptions in 50 sample villages randomly selected in the study area. The procedure is described and documented in the previous chapter. The evidence layers used for building the expert system were also used to create a GIS map by an overlay operation and the final map was reclassified in three main categories (low, medium and high). Similarly to the procedure used for the expert system, the GIS overlay and the output maps of the nutrient budget and the vegetation trend mapping models have been evaluated against the participatory land degradation map based on the farmers' perceptions. After this validation procedure, a spatial analysis was performed in the GIS to compare the land degradation maps created by these different methods.

5.2.5 Analysing the impact of different land management scenarios

In general, participatory land management implemented through the approach *Gestion des Terroirs* is concerned with the management of human as well as physical resources. It aims at both maximizing livelihood subsistence and minimizing the negative environmental impacts that threaten long-term sustainability (Engberg, 1993; Lewis, 1996; Capo-Chichi et al., 1995).

Table 5.3: The different scenarios and their main contributing variables

	VARIABLES INVOLVED													
SCENARIOS	Vegetation density	Manure availability	Presence of erosion	Grazing intensity	Institutional capacity	Local coping capacity	Farming system	Immigration	Population density	Rainfall erosivity	Slope	Soil	Tenure systems	Fuel wood demand
Agricultural development	X	X			X	X	X				X	X		
Environment conservation	X	X		X	X	X			X			X	X	X
Income raising	X	X			X	X	X					X		X
Social development		X		X	X	X	X	X	X				X	X
Erosion control	X		X							X	X	X		

In the study area, the objectives of the local land management plans were specifically: (1) increasing agricultural production; (2) improving environmental conditions; (3) increasing household incomes; and (4) improving the general social welfare of the local population. For this, different (physical) land management and socio-economic activities are implemented in the study area with the support of the PNGT (Programme National de Gestion des Terroirs). These objectives served as a basis to define possible scenarios that could generate different levels of land degradation. The rationale is that, in developing each scenario, specific variables will contribute more than others to the overall effect on land degradation. As noted in Lein (1993), to avoid overloading the decision-making process with information, developing a scenario requires listing all processes and events potentially relevant to the specific problem (combining expert judgement with technical and physical data) and selecting only the necessary elements.

As shown in Table 5.3, we selected and weighted more the most important variables in each scenario, contributing to the implementation of a "what-if" analysis in the expert system. In the knowledge base, the conditional probabilities of the variables only involved in each scenario remained the same as those initially used to build the expert system. By executing the expert system for the scenarios, different maps were created. These maps were compared with the initial results of land degradation mapping by the expert system, which involved the input of all the evidence layers. The comparison between the different maps was used as a basis to analyse the sustainability of the different local land management systems, as well as to assess the sensitivity and consistency of the expert system in the different input scenarios.

5.3 Results

Figure 5.2 shows different maps of land degradation, resulting from the different assessment methods. The initial map created by the expert system used all the indicators of land degradation, based on the rules derived from local knowledge and farmers' perceptions in the study area. To evaluate the outputs of the different methods against the participatory land degradation mapping data, the confusion matrices (or error matrices) were calculated for the different maps. This assessment gave an overall mapping accuracy (calculated at 95% confidence interval) of respectively 82% for the expert system, 61% for the nutrient balance model, 60% for the GIS overlay map and 36% for the vegetation trend map.

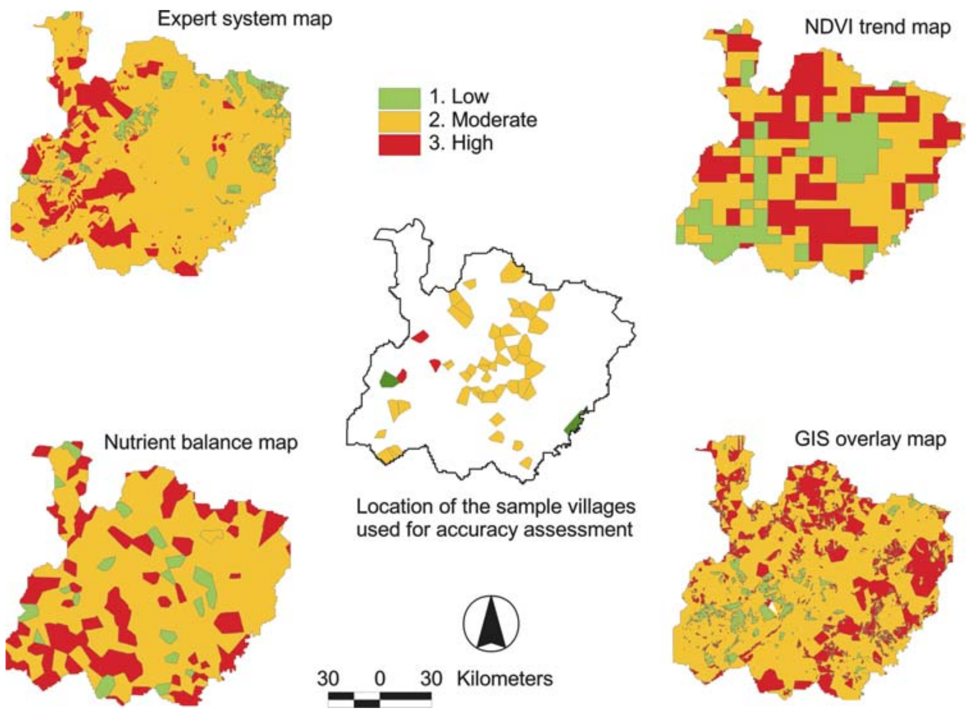


Figure 5.2 Different methods of mapping land degradation in the study area

The error matrices showing the results of the evaluation the outputs of nutrient budget and the vegetation trend mapping models against the output of the expert system are summarized in Table 5.4. The overall accuracy (percentage overlap between the same classes of degradation) is 68% with the nutrient balance map and 42% with the vegetation change map. It shows that, in the nutrient balance map, there is a relatively high percentage of overlap for the areas classified as moderate and high (respectively

74% and 54%), while the class of low degradation has only 14%. As regards to the vegetation trend map, the percentage of matching with the output of the expert system is low for all classes of degradation.

Table 5.4 Percentage overlap between the different classes of the expert system map with the nutrient balance map and the vegetation change map

	Nutrient balance map				Vegetation change map			
Expert system map	Low	Moderate	High	Total	Low	Moderate	High	Total
Low	14	46	42	100	14	54	32	100
Mod	7	74	19	100	22	46	32	100
High	46	0	54	100	16	53	31	100
Total class accuracy	6	68	25		5	80	15	

Overall matching accuracy with the expert system: 68% for nutrient balance, 42% for vegetation change

The spatial distribution of the land degradation classes (percentage of the total area) for the output map of each method is summarized in Table 5.5. It shows that every method predicts the smallest size for low land degradation areas, while the moderate land degradation areas are predicted at the largest size. The comparison of the different maps show that the largest size of moderate land degradation areas is predicted by the expert system (80%).

Table 5.5. Spatial distribution of land degradation classes for the output map of each method of land degradation assessment

Land degradation classes	**Expert system map**	**Nutrient balance map**	**Vegetation change map**	**GIS overlay map**
Low	5	6	21	4
Moderate	80	69	48	72
High	15	25	32	24
Total	100	100	100	100

Figure 5.3 maps land degradation as predicted by the different land management scenarios using the expert system. Figure 5.3a is the initial output map of the expert system using the probability matrices built with the local farmers. From a visual check, some similarities can be noted between the initial map and the output of the environmental conservation scenario. Visual similarities can also be noted between the outputs of the agricultural development scenario and the income-raising scenario.

Figure 5.4 shows the results of the error matrices, calculated based on the evaluation of the output maps of the different scenarios against the initial map of expert system. There is a high percentage of overlap with the output of the environmental conservation scenario (82%). The overlap with the outputs of the other scenarios was respectively 69% for agricultural development, 68% for income raising, 64% for social welfare and 64 % for erosion control.

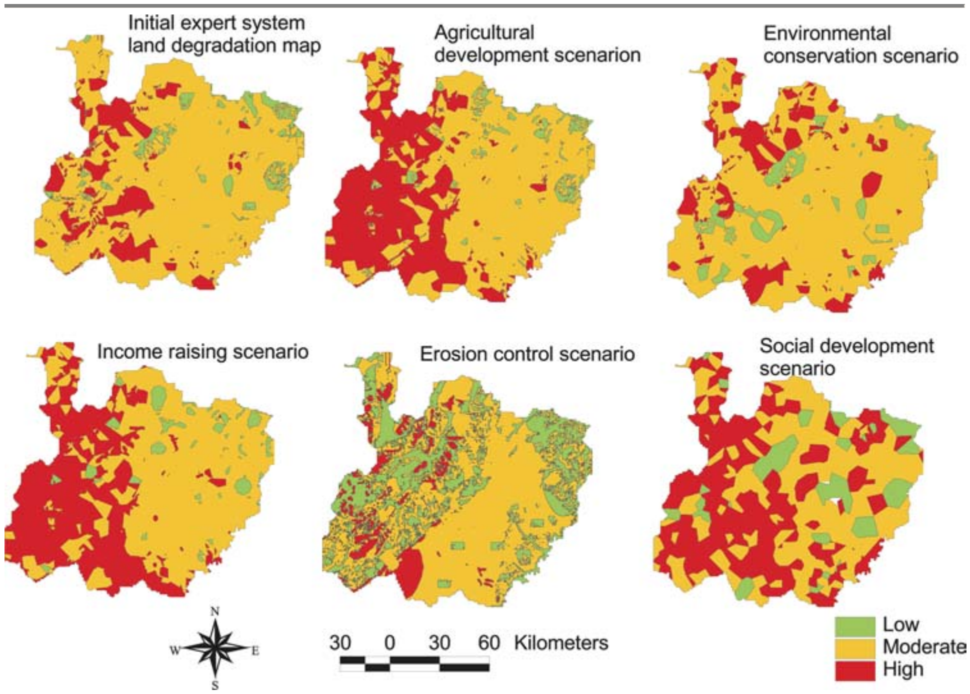


Figure 5.3 Maps of predicted land degradation based on the different scenarios and using the expert system

Figure 5.4 shows also the results of the error matrices, calculated based on the evaluation of the output maps of the different scenarios against the nutrient budget map.

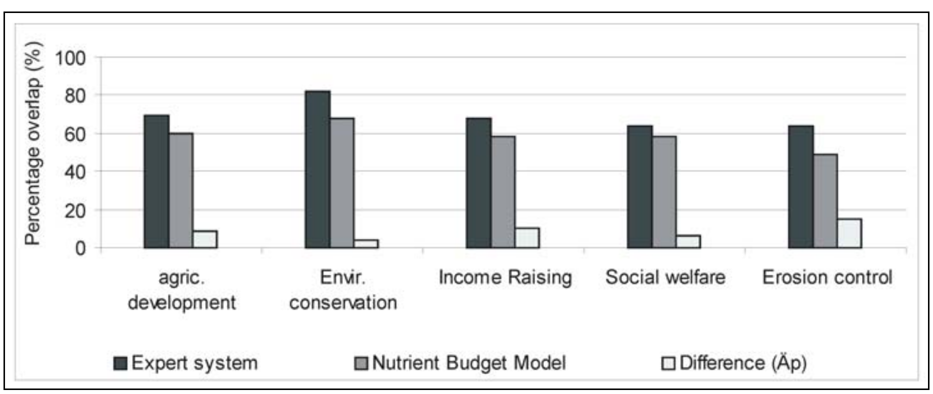


Figure 5.4 Percentage of overlap between the outputs of the two methods (expert system and nutrient balance model) and the outputs of the different scenarios.

It gave respectively 68% for the environmental conservation, 60% for agricultural development, 58% for income raising, 58% for social welfare and 49 % for erosion control. The figure shows also the difference (Δp) between the percentages of overlap for the different scenarios, using the expert system and the nutrient balance. It was respectively 9% for agricultural development, 14% for environmental conservation, 10% for households income raising, 6% for the social welfare and 15% for the erosion control scenarios. The spatial distributions of the land degradation classes (percentage of the total area) predicted by the different scenarios are summarized in Table 5.6.

Table 5.6 Spatial distribution of degradation risk classes for the different scenarios, the nutrient balance model and the vegetation changes

Land degradation classes	Agricultural development	Environment conservation	Income raising	Physical assessment	Social welfare
Low	4	8	4	25	12
Moderate	61	78	59	67	46
High	35	14	37	8	42
Total	100	100	100	100	100

These results show that the predicted proportion of moderate degradation areas is the highest for all the scenarios, the percentage ranging from 46% (social welfare scenario) to 78% (environment conservation scenario). Except for the erosion control, the low degradation areas predicted by the other scenarios have the smallest proportion.

5.4 Discussion

5.4.1 Analysis of the different methods of mapping land degradation at regional level

The expert system, more than the two other models used for assessing land degradation at regional level, obtained the results closest to the perceptions of the local people. From a technical perspective, many explanations can be given.

- The first reason may because of the wider range of variables involved in building the expert system and the use of the (farmers') expert rules for combining these variables. This increases the ability of the expert system to represent land degradation as perceived by the local farmers in a better way than the nutrient budget model, which used only two of the variables involved in building the expert system: farming systems and manure availability. Based on this argument we can conclude that expert systems are more adapted for qualitatively assessing land degradation as perceived by the local farmers and to evaluate the level of sustainability of the local land management systems from a regional perspective. This is also in agreement with Scoones and Toulmin (1998) that the lack of consideration for the local socio-economic context issues reduces the efficiency of nutrient models to oriented policy measures.
- An other reason may be that the participatory mapping based on the farmers' perceptions is not well adapted for evaluating the quantitative models such as the nutrient budget and the vegetation trend-mapping model.

- Finally in the specific case the vegetation trend model, the low spatial resolution of the NOAA images could be an important source of mapping errors. A pixel size (7.6 km by 7.6 km) covers in some cases more than a village area, inducing generalization errors in the vegetation change analysis.

The study demonstrates the ability of the expert system to operate as a simulation model. It shows that an expert system can be operationally used to evaluate the impact of human (land management) activity and the potential risks to environmental stability over the long-term. Even tough the time factor was not directly considered in the study, it is included in the reasoning of local people, who always refer to a long-term process in choosing their indicators of degradation. By capturing and integrating their perceptions and knowledge in the expert system, the final result does not reflect a simple static statement but rather a longer-term exploration of the dynamics of the system.

The comparison with the results of the evaluation using the output of the nutrient budget model shows somehow the consistency of the expert system. The differences of overlaps between the outputs of the two methods with outputs of the different scenarios gave in all cases a positive value (Δp ranging from 6 for the social welfare to 15 for erosion control).

5.4.2 Analysis of the impact of the different scenarios on land degradation

As shown in Table 5.6, the scenarios of increasing agricultural production and household revenues predict a deterioration the of land degradation. These scenarios show a minimal proportion of low degradation areas (4%) and an important proportion of high degradation areas covering more than one third of the province. This suggests that, despite the farmers increasingly using chemical and organic fertilizers, greater intensification is needed. However, an important reason may be linked to the use of cattle manure, which is an important component of agricultural intensification. Many villages have few livestock (especially in the southwest of the province where more degraded areas are also predicted). For instance in the district of Toussiana the number of livestock per village is very low as compared to the rest of the province. The average livestock number per household is around 0.8 TLU while it is more than 3 TLU at the provincial scale. This affects the agricultural intensification capacity of the farmers who, in majority rely on organic fertilization. Consequently, increase in soil mining and deforestation are expected (increasing agricultural production can only be achieved by extending cultivation areas).

The scenario of erosion control predicts the least land degradation. Only 8% of the total area is severely degraded while up to 25% of the area has low degradation. This favourable situation suggests once more that, despite the threatening process feared by environmentalists, the degradation (in absolute values) is still acceptable because of the good physical parameters in the province: soil generally good, abundant vegetation, important rainfall and gentle slope.

The least situation arises with the scenario of promoting social welfare, which predicts that nearly half of the area will be degraded. In this scenario, most of the socio-economic factors are not favourable for many villages (unfavourable tenure regimes, long distances to market, low presence of technical services, high wood harvest as a source of income). For example, (Sedogo and Groten, 2001) showed that nearly 50% of the villages are predominantly inhabited by immigrant agriculturalists and pastoralists. These groups have limited rights for implementing land management activities (the tree plantation and the implementation of soil and water conservation activities are often prohibited).

The overall accuracy of 82% obtained with the evaluation scenario of environmental conservation against the initial output of the expert system suggests that farmers' perception of land degradation are mostly influenced by environmental considerations. This could be explained by the fact that the rural population in Burkina Faso is very much aware of the environmental problems, specifically desertification. On one hand, the natural conditions in the country during these last decades could have contributed to this situation (i.e. the severe draught in 1973-1974 and 1984, frequent rainfall shortage). On the other hand, the government, together with international donors and NGOs, emphasised environmental issues so strongly that it has sharpened the understanding of the concepts at the grassroots organisations. This has also contributed to stimulate farmers' participation in the implementation of adequate measures.

Finally, the study shows that expert systems could positively contribute to improving the orientation of local planning and policy measures. Indeed, during the process of building and implementing the expert system interactively with the local people, we could identify the factors contributing to the degradation processes. The participatory procedures used for validating the expert system allowed the determining the strength of each factor in the general process. Even though this is not directly reflected in the end result of the expert system, the results of these procedures can be recorded for later use to orient planning and land management activities. For example, the implementation of the procedure in the sample villages belonging to the district of Toussiana (southwest of the province) revealed that the farmers were more concerned about the problem of soil acidity than about soil erosion control as initially diagnosed during the planning process. Such an error contributed to the failure of land management projects because the farmers failed to contribute to realizing the conservation measures.

5.5 Conclusion

The study shows that the results of expert systems to assess the sustainability of land management systems agreed better with the PRA assessment of land degradation than other technical methods such as the nutrient budget model and vegetation trend analysis using NOAA data. The expert system allowed the integration of a wider range of factors, using a rule base reasoning for a more holistic assessment of land degradation and sustainability. The study did not take into account the time factor, which is an important component of the concept of sustainability. However, this is included in the reasoning of local people, who always refer to a long-term process in choosing their indicators of degradation. The study shows that the expert system can be implemented as a simulation model, used to predict the potential impact different land management scenario on the overall status of land degradation. The procedure of building and validating the expert system interactively with local people offers the advantage of decomposing the general process of degradation into its (physical, social and economic) sub-processes. Finally based on the results of this study we can conclude that an expert system is a convenient tool for integrating local knowledge in GIS, contributing to bottom-up regional planning. We recommend further research that aims to:

- Optimise the spatial variability in the application of the decision rules, which are not necessarily the same for all villages in the province;
- Find additional independent indicators for verifying the effectiveness of projects and programmes from the local perspective.

Acknowledgement
I wish to thank the staff of the PNGT project and the regional extension services in Bobo-Dioulasso for their support and collaboration during the field visit to the study area. My special thanks to the members of the planning committees of the sample villages, for their kind and warm collaboration during the PRA surveys.

CHAPITER VI[*]

CONFLICT RISK MAPPING IN BOTTOM-UP REGIONAL PLANNING: A PATIAL APPROACH LINKING PRA, SOCIO-ECONOMIC AND REMOTE SENSING DATA

∗ This Chapter is based on This chapter is based on L. G. Sedogo, S.M.E. Groten , Mc Call, M., Marta-Cassusso, B. (*in review*) The Geographical Journal

Abstract

This study presents a method that links Participatory Rural Appraisal (PRA), socio-economic and remote sensing data with a GIS in bottom-up regional planning. It is based on a case study of a participatory land use planning project involving 17 villages around the forest of Maro, located in the northern part of the province of Houet in southwestern Burkina Faso. The stakeholders involved in the planning process are identified and a typology of the main existing and potential conflicts based on a multiple key is proposed. To arrive at these results we first analysed the information collected from PRA surveys in the different villages involved in the participatory land use planning project to map the potential conflicts that may occur in the project area. Secondly, we analysed the individual and collective interview data collected with 250 farmers in 50 sample villages of the province, to identify the factors perceived by local people as the main causes of conflicts. Population pressure was identified as the principal cause of existing and future conflicts and it was used to derive pressure indices on cultivable lands and rangelands that were used to map the potential conflict areas. The number of land use conflicts aggregated at the district level was used to test the hypothesis that the intensity of conflicts is a function of the competition for land, the insecurity in land rights and the absence of authority (weak institutional representation and policy instruments).

6.1 Introduction

This study presents an approach for predicting and mapping conflict risk in bottom-up regional land use planning using PRA and remote sensing data in a GIS. Conflict is natural and will always exist (FAO 1998/1999), and a land conflict is a natural phenomenon, which refers to the legitimate but opposing interests. However in most African countries, natural resources-related conflicts have become burning issues during the last decades. Examples exist in many places where disputes over access and use of resources between individuals or groups have turned into uncontrolled violent political eruptions (e.g. in Rwanda and Burundi). But beyond the negative connotation that is generally associated with conflicts (Rodriguez, 1994; Walker and Daniels, 1999; Upreti, 2001), the competition for resources may be a sign of positive functional improvements towards more integration, community building and progressive economic and social changes (Buckles, 1999; Upreti, 2001, Warner and Jones, 1998; Gray and Kevane 2001). In any case, setting up clear procedures and mechanisms of conflict prediction and management is a prerequisite for the sustainable management of natural resources.

In Burkina Faso a local participatory land management7 approach is being implemented on a large scale. Mechanisms providing relevant conflict analysis, prediction and management processes should necessarily accompany the planning process for three main reasons. Firstly, conflict mapping is an essential mechanism that make it possible to forecast the spatial impact of the behaviour of the land users and their decisions that affect all those involved in the management and use of the natural resources. Secondly, in the context of rapid socio-economic and ecological changes, conflict situations that can jeopardize the planning process may be avoided by identifying these critical areas where special sharing or reallocation rules are necessary. Thirdly, participation involves negotiations between stakeholders who have different views and interests in the management units (FAO/UNEP, 1995) and, therefore, identifying and mapping functional or structural conflicting areas can improve the negotiation process.

Despite the importance of the issue, identification of the real causes as perceived by the main actors, which is needed to set up the necessary prediction or management mechanisms, is often restricted to narrative and popular thoughts. Firstly there is a distinction between conflicts over facts, and conflicts over interests. Obermeyer (1994) differentiates between *"cognitive (fact) conflicts"* which are relatively superficial disagreements about the facts behind a dispute – though there are always more than enough 'facts' for each party to be selective about which to use, and how to interpret them, - and *interest (value) conflicts,* which relate to the parties' cultural or social values. There is a further and deeper distinction within the "interest (value) conflicts" (Wehr 2001).

7 The *Gestion des Terroirs* approach is meant to involve the transfer of control over the management and use of natural resources from government structures to local people, and to include programmes supporting improved management of and investment in a variety of methods aimed at increasing yields within crop, livestock, and forestry production, and assuring a greater reliability of such yields.

They may correspond to short-term Interests - the more immediate, specific *objectives* of the parties, which have led to the current competitive behaviour. Or, 'interest conflicts' may reflect deep-rooted values of the parties - underlying, long-term *interests* or *motivations* - security, recognition, respect, justice, or for that matter, the fears of parties regarding other groups.

A reason often cited for the prevalence of conflicts is that both traditional and modern national systems are failing to safeguard the security of access to natural resources for people in rapidly changing societies (Thieba et al., 1995; Tallet, 1999; Gray and Kevane, 2001). Open and (most often) latent or hidden conflicts are said to arise because of structural scarcities and inequalities due to the non-equity of access and sharing of resources (Boerboom, 1999; Hueting and Reijender, 1998). It is also argued that the high pressure on the land (attributed to the high population growth and the decline in potential of the natural resources) and the shift towards more market orientation of the rural economies are contributing to exacerbate competition for basic resources (Blench, 1997; 1998; Pare, 2001). Frequently, conflicts erupt between users interested in exploiting the land for the same function (in agriculture, arable *vs* pastoral land use), and to a lesser extent when different functions are involved, for example, production *vs* protection (Blench, 1998). Thus, there is an assumption that as the competition amongst the users intensifies, there is bound to be increasing conflicts in both frequency and intensity, with risks of escalation into uncontrolled situations. The socio-economic and political context may also be the trigger for the emergence of conflicts, especially as the authority of most central governments has been undermined by external factors such as the impact of Structural Adjustment Programmes.

The underlying causes of most, if not all, interest (value) conflicts have a historical dimension of previous conflicts, which precede the current conflict being analysed. Such prior conflicts may have been in different arenas or over different resources, nevertheless they represent sustained *contests* between the relevant parties. Therefore, even where the immediate causes may be new economic or demographic pressures, conflicts are frequently reinforced by historical, deep-seated, (and maybe latent) contests which have their structural roots in unresolved inequities between socio-economic classes, castes, ethnic groups, tribes, clans, regional groupings, religious factions, language groups, political factions, genders, age groups, etc.

The sources of conflicts are well summarized in the hypothesis posed by Thieba et al. (1998) that: conflicts are functions of the competition (for land), the insecurity in land rights, and the absence of authority (weak institutional representation and policy instruments). In a context of bottom-up regional land use planning, a thorough investigation to understand the contribution of these factors to existing or potential conflicts is needed based on the views of the local stakeholders.

Conflict analysis should be based on the principle that all the parties in the conflict have some moral legitimacy to their interests. To this extent, they therefore have a right to express and articulate their interests. Sustainable NRM cannot begin with the assumption that there are overriding “correct” or “acceptably legitimate” claims to resources and their use. Bell et al. (1989) have distinguished 3 main types of methods useful to analyse conflict situations: interpretative, abstractive and prescriptive analysis.

Interpretative analysis have been often used to examine conflicts on natural resources by analysing their structure, processes, function and their relationships, as well as the pattern of interaction among people (Upreti, 2001, Warner, 2000, Blench, 1998, Warner and Jones, 1998, Banzhaf et al., 2000). Most answers sought by these empirical studies on conflict in natural resources management stem from questions such as: who? (stakeholders and their interests and goals), what? (types of conflicts and resources involved), why? (reason for conflict). The abstractive method dealing mostly with the behavioural analysis of individual involved in conflicts are less common in conflict analysis. For both methods however, the spatial dimension, which is one of the key issues of conflicting situations in natural resources management, is also the weak point. Prescriptive analysis provides a rational basis to advise people on what they should do to make better choices. It means finding what thoughts, decision aids, conceptual schemes and methodology are useful for people (Bell et al, 1989, Kremenyuk, 1991, Upreti, 2001). As such it is founded on decision support models, using tools such as multiple criteria and trade off analysis, goal programming etc. that gained importance in conflict assessment methods (v.d Toorn et al, 2001, Malczewski, 1997, Ellis, 1997, Janssen, 2001) used to support land use planning.

Our approach in the present study combines both interpretative and prescriptive analyses in order to determine the main causal and predictive factors of conflicts on resource use in the study area. For this we examine the conflicts as perceived by the local people and we derive the main causes using Participatory Rural Appraisal (PRA) and questionnaire data. These factors are linked with PRA information collected at a participatory land use planning project area level, and regional socio-economic and remote sensing data to map the area at risk for different types of conflict at the different levels. We use a regression model to predict the number of conflicts at an aggregated district level, based on factors of pressure indices on agricultural and pastoral lands, availability of surface water (for cattle watering), percentage of villages with a dominant immigrant population per district, and an index of the presence of technical services per district.

6.2 Methods

6.2.1 The study area

The study area is the province of Houet located in southwestern Burkina Faso (see Figure 6.1). The annual rainfall ranges between 800 and 1200 mm and the main cropping systems are rainfed cultivation (extensive cereals and semi-intensive cotton), irrigated rice, fruit trees and small-scale market gardening. Extensive livestock farming is increasing due to the clearance of the tsetse fly, the contribution of cotton revenues and the impact of migration from the arid northern areas. Despite being relatively wealthy in terms of natural resources compared to the rest of the country, the area is degraded due to a combination of factors. Despite a relative improvement of household income in the province due to cotton cultivation, conflicts about resource use are more and more issues of concern for local people and regional authorities, due to the impact of key factors: high population pressure, unstable rules in customary tenure systems and statutory laws. These factors are exacerbated by an increasing livestock population and a high immigration rate.

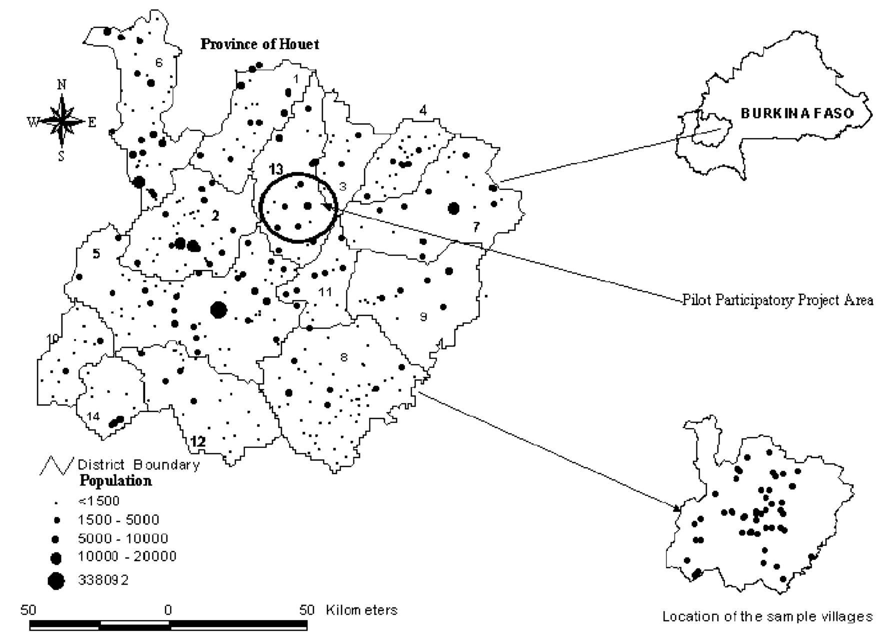


Figure 6.1 The study area. Location and population sizes of villages and cities. The biggest spot represents the city of Bobo-Dioulasso, whose population was estimated at 338,092 (source: regional planning service based on national census in 1995)

The overall population of the province has tripled in twenty years, from 306,670 in 1975 to 585,722 in 1985, then to 935,345 in 1995. This increase can be attributed to the rapid growth of the urban population, which represents more than 50% of the total population of the province. However, the high immigration rate of farmers and pastoralists from the central and northern parts of the country is seen as the most important factor of rural population growth. In 1991, the population of immigrants was estimated at nearly 40% of the overall population (source: regional planning service). Within 15 years (1984 – 1999) the total agricultural area increased by about 75%, from 131,700 ha to 233,800 ha (source: national service of agricultural statistics). Livestock is also rapidly increasing due to the fact that farmers are increasingly investing their revenues from cash-crop cotton cultivation in livestock, and also due to the migration of cattle from the north. For these reasons, the province was chosen as a pilot area to start implementing a participatory land management approach. Financed by the World Bank, a pilot project was initiated in 1992 around the Maro Forest (see Figure 6.1) with the objective of conducting sustainable land management based on participatory planning, while improving the local social conditions by increasing household income.

Table 6.1 Number of villages, population and distribution of immigrant and pastoralist villages per district.

District -ID	District	No. of villages in the district	Dominant native ethnic group in the district	District Population	Villages where dominant population is immigrant		% Villages with dominant pastoralist population
					No. of villages	% Villages	
1	BADEMA	23	Bobo	52,986	23	100	0
2	BAMA	35	Bobo	71,948	17	49	6
3	BEKUY	10	Bwaba	24,999	8	80	0
4	BEREBA	29	Bwaba	24,857	15	52	3
5	BOBO	59	Bobo	93,171	2	3	9
6	FO	44	Bobo	82,364	27	61	0
7	HOUNDE	25	Bwaba	58,882	7	28	8
8	K_VIGUE	58	Vigue	42,903	33	57	0
9	KOUMBIA	12	Bwaba	25,136	5	42	0
10	KOURINON	16	Toussian	13,726	1	6	6
11	LENA	14	Bobo	20,608	0	0	7
12	PENI	23	Tiefo	25,859	2	9	9
13	SATIRI	18	Bobo	39,956	4	22	11
14	TOUSSIANA	9	Toussian	24,356	0	0	0
Total		**375**		**601,751***	**144**	**38%**	**5%**

*: Excluding the urban population

The Maro Forest and the Hippopotamus conservation lake are two protected areas located in the northwest of the province. During the pilot phase of the project (1992 – 1996), an integrated land use plan was initiated in that area by the PNGT with the following components:

- Participatory management of the Maro Forest by an inter-village committee representing 17 villages surrounding the forest with the multiple objectives of raising income for the local people, supplying fuel wood to the province capital, and conservation of the forest;
- Delineation of a local pastoral zone to provide security to the pastoralists living in the area while avoiding the increasing pressure of cattle on the reserve areas;
- Protection of riverbanks against soil erosion and sedimentation;
- Definition of local conservation areas to protect village cultural sites.

Based on the positive results of this experience, the government started a sustainable land management programme at regional scale for the period 2001- 2006.

6.2.2 Data collection

PRA data from surveys conducted in the villages of the project were obtained from the PNGT programme. Primary and secondary socio-economic data for different levels were also used, including:

- Household survey data from the villages of Kadomba and Bala, belonging to the PNGT pilot project area;
- Group interview data collected in 50 sample villages in the province, with the members of village planning committees;
- Individual interview data collected with 250 farmers randomly selected in the 50 villages.
    - ► A regional socio-economic database containing data collected in every village of the province in 1996. From this database, the following variables were used for the study:
    - ► Population data per village for the years 1975, 1985, 1995 (based on the national census) including the dominant (in number) ethnic group.
    - ► Socio-economic data: infrastructure (schools, health centres, wells, markets) number of cattle, technical services and NGOs, number of socio-professional organizations.
    - ► Technical information: land management activities implemented, size of irrigated lands.
    - ► The dominant type of conflicts occurring in each village.
    - ► Interviews were conducted with the provincial commissioner and 5 (out of the 14) District Commissioners in the province on the issue of conflicts.

GIS layers included a land suitability map digitised from a regional agricultural suitability map sheet at scale 1:500,000 (ORSTOM, 1976). A village point map of the province was converted into a polygon map using “Thyessen polygon” interpolation, in an attempt to substitute for a missing map of village boundaries. Other thematic coverages also included a digital map of the reserve areas in the province, and other attribute maps derived from the socio-economic database. Vegetation index (NDVI) data were downloaded from the Africa Data Dissemination Service (ADDS) website (http://edcintl.cr.usgs.gov/adds). The time series spanning the period between 1990 and 1999 were imported in WINDISP software and clipped to the window corresponding to the coordinates of the study area in western Burkina Faso. The maximum yearly NDVI value image of the period was extracted and converted into GIS coverage. After a transformation into the UTM coordinate system, it was spatially joined to the village map in order to give the maximum NDVI value for each village. This method was considered experimental due to the coarse resolution of the NDVI data used (7.6 km).

6.2.3 Methods of analysis and conflict risk mapping

The following methods were used for analysing the factors contributing to risk of conflicts in the study area.

- *(1) Stakeholder analysis and typology of conflicts*

The results of an interactive system analysis realized in previous studies in the study area were used to determine the main processes of the local land management systems, the major land resources, the land utilization types and the stakeholders involved. The PRA data and the interviews conducted in the different villages were also used to determine the interactions between the different groups, their interests and their relationships with the natural environment. The major (existing and potential) conflicts occurring in the area were identified and classified according to the type, the category of the main cause, the scale and the stakeholders involved.

- *(2) PRA tools for conflict analysis*

The information extracted from the PRA data was used to identify the existing and potential conflicts, both at a village level (in the case of Kadomba) and the project area level (participatory land use planning around the Maro Forest). The different tools used for this included: diagrams drawn by the planning committees (organization diagrams and diagrams of the production systems), land use sketch maps of the villages, and a classification matrix showing the preferences of the local stakeholders towards the different resource types.

- *(3) Statistical analysis determining the factors of conflict risk at regional scale*

The individual and group interview data in the 50 sample villages were statistically analysed to determine the main factors contributing to existing or potential conflicts. These factors were used for mapping conflict risks at the different levels of land management as follows:

- *1. Conflict risks on cultivable lands*

The land / person ratio, which indicates the quantity of cultivable lands potentially available per person in a certain area, is often acknowledged in the literature as a good parameter to assess the impact of the population pressure on land use (Verheye, 1997). In this case it was used as an indicator of risk of disputes over cultivable lands, as the population pressure is perceived by local people as a major factor of the competition leading to conflicts. We determine this ratio from the equation (1) with values ranging form 0 to 1:

$$Rc = \frac{Cult\_lands}{Avail\_lands} \quad (1)$$

where:

- Cult_lands represents the total agricultural areas used by the population in each village.
- Avail_lands = Total village area (non-suitable lands + regional planning units area), representing the potential usable lands.

The size of the cultivable lands for each village was computed based on the average farm size per household in the province derived from the regional statistics. In the absence of a real administrative boundary for each village, indicative village areas were estimated based on the Thiessen polygon interpolation method. The areas not suitable for agriculture were identified on a regional suitability map (Boulet and Leprun, 1969).

Based on the same method, an index was computed showing the dynamic of the pressure in each location, for the period between 1985 and 1996 using census data for the two periods.

2. Conflict risks Agriculture/ Pastoral

Following the same reasoning as above, we used the pressure on rangelands as an indicator of pastoral land use conflict risks using the equation (2):

$$R\,a\,/\,p = \frac{Req\_Pastland}{Avail\_Pastland} \quad (2)$$

where: Req_pastland is the size of pastoral lands required to sustain the livestock population for each village. It is obtained by the equation (3):

$$Req\_Pastland = \frac{Qu\_Fora}{Biom} \quad (3)$$

where: Qu_Fora is the quantity of forage necessary for feeding the cattle in each village, based on the fact that one Tropical Livestock Unit (TLU) consumes on average 6.25 kg of forage every day (source: Boudet, 1978).

Biom is the quantity of forage effectively available at village level derived from biomass estimates in Burkina Faso using NDVI data (Groten, 1991) in equation (4):

$$Req\_Pastl = 11185.5 * NDVI - 757 \quad (4)$$

Avail_Pastland is the size of the potential pastoral lands available in the village. Because the pastoral lands are considered as residuals of the agricultural areas (Sedogo and Groten, 2000), they were obtained by subtracting the agricultural areas (plus the reserve areas) from the total village area.

The following variables were identified from socio-economic factors and the results of the above procedure, to derive a predictive function of the likelihood of conflicts through a multiple linear regression:

- Pressure index on cultivable lands representing an index of the pressure on agriculture lands.

- Pressure index on pastoral lands representing an index of the pressure on pastoral lands.

- Percentage of villages with a dominant immigrant population in the district.
- Cattle watering capacity based on the number of villages per district having surface water during the dry season.

- Institutional capacity, based on the number of technical services per district, which shows the technical capacity of supporting local land use planning activities.

A correlation was used to select the list of independent variables to be used in the regression. The number of conflicts was aggregated at district level, by summing the number of villages where land use conflicts have been reported. This was used as the independent variable.

6.4 Results

6.3.1 Stakeholder analysis and typology of main conflicts in the study area

- *(1) The main stakeholder groups.* Based on the classification used by INERA (1998), two major groups were identified based on the dominant socio-economic activities of local communities living in the area. One group consists of agriculturalists who practice an extensive rainfed agriculture and also keep herds of small ruminants (goats and sheep) and poultry. This is the dominant group composed mainly of native and immigrant (Mossi) farmers. The other group consists of agro-pastoralist/ herdsmen. They belong to the socio-cultural group of Peulhs or Fulani, who are traditionally nomadic herdsmen, but who now tend to settle and practice subsistence farming to complement their main activity of extensive livestock farming based on relatively big cattle herds. In between these two, a relatively new group is emerging of so-called agro-pastoralist agriculturalists (Sanou et al., 1998), whose activities are oriented toward a mixed farming system combining agriculture and small-scale semi-intensive livestock production. Hunters also constitute an important group that traditionally plays a significant role in the socio-economic and cultural life of the community. Other socio-economic groups involved in specific activities relying on natural resources and gender groups can also be identified.The groups of outsiders having an impact on local natural resources compose the indirect land users. These are essentially local and regional authorities, regional services, NGOs and projects intervening in decision making related to the use or management of resources.

- *(2) Typology of conflicts* A lot of literature has been written on conflicts, mediation and negotiation, which distinguishes different types of conflicts in terms of the contrasts in goals and objectives, the levels of gains or losses between parties, or the degree of non-negotiable issues (such as fundamental rights or societal identity) at stake (Cousins, 1996). We based our classification of the main types of conflicts upon the following keys (see Table 6.2):
- The category of conflicts
- The causes of conflicts
- The spatial scale (in the local to regional continuum)
- The stakeholders and arenas.

Table 6.2 Typology of conflicts in the study area

Category	Cause	Scale	Stakeholders and arenas
Agriculture	Population pressure, cultural changes	Intra-community and Inter-group	Landless/ owners Natives / immigrants
Agriculture/ pastoralism	Population and livestock increase	Inter-group	Cultivators / pastoralists
Hunting/ pastoralism	Land degradation	Inter-group	Native hunters/ pastoralists
Forestry/ pastoralistm	Land degradation	Inter-group	Wood exploitants/ pastoralists
Agriculture (irrigation)	Land management	Inter-village	Village / village
Agriculture/ pastoralism	Land management	Inter-group	Irrigation exploitant/ pastoralists
Fishery	Resource degradation	Inter-group	Natives/ immigrant fishermen
Local to regional (e.g. forestry)	Top-down policy	Semi-regional (Project area)	Local communities/ regional authorities

6.3.2 Analysis of the factors contributing to conflicts

- *(1) General perceptions of conflicts*

According to the information obtained from the district authorities and key informants, conflicts have always been part of the social life of the local communities. Nevertheless, as shown in Table 6.3, the perception of insecurity among the main local groups, regarding the issue of conflicts in land and resources management in the sample villages, is relatively low. As shown in the table, the different groups experience relative security, even though the immigrants and pastoralists feel more insecure than the natives.

- *(2) Conflicts between natives and immigrants*

The general perception of relative security is reinforced by the low importance of conflicts as perceived by the majority of farmers interviewed (58% in Table 6.4). Table 4 shows also that the degree of integration of the immigrant cultivators among the native population is relatively high (72%). A widespread opinion among the natives is that the immigrants have brought positive social and economic changes for most of the villages, such as improved social relationships in terms of mutual aid, promoting political and administrative considerations, increasing agricultural production, and more importantly promoting trade. As shown in Table 6.4, conflicts between immigrants and natives are mainly (66%) caused by the reduction of living space, due to the population increase. Land use issues also account for more than 25%. Resolution methods based on traditions (54%) or individual agreements (44%) are preferred to modern ways of resolution (administration or court).

- *(3) Conflicts between cultivators and pastoralists*

According to the information obtained from the district authorities and local key informants, this category of conflicts is dominant both in frequency and in the spatial dimension. This information is confirmed by the results of individual interviews in the sample villages listed in Table 6.5, showing that the majority of villages are faced with very frequent conflicts (58% of responses). However, the majority of the people interviewed (72%) find that the presence of pastoralists is necessary. Table 6.5 also shows that in the large majority of cases (92%) the conflicts that take place during the rainy season occur in the remote fields (*champs de brousse*). Conflicts occurring during the dry season are due to conflicts between agriculture and livestock farming (destruction of harvested crops, orchards and gardens by cattle).

- *(4) Dynamics of village conflicts*

As shown in Table 6.6, the analysis of the information collected through interviews in the sample villages (n = 50) showed that the large majority, more than 90% of the villages, had not experienced past or recent conflicts over agricultural lands. However, past and recent "agriculture / pastoral" conflicts are quite important (respectively 54% and 58% of the villages). Table 6.7 shows how the local farmers perceive the future projection of conflicts in their villages. As shown in the table, 76% of the farmers foresee an increase in both the number and severity or conflicts. The main reason cited (69%) is population pressure. Despite being perceived as relatively less important, the cultural differences and tenure issues (respectively 6% and 5%) are expected to significantly contribute to increasing the conflicts, more than land degradation and land policy.

Table 6.3 Perceptions of degree of security for the different groups (n = 250)

Feeling of:	Native population (n = 120)	Immigrant farmers (n = 80)	Pastoralists (n= 50)
Security	89%	84%	77%
Insecurity	11%	16%	23%
Total	100%	100	100%

Table 6.4 Perceptions of the integration and conflict issues between native population and the immigrant farmers

Acceptance of immigrants by natives	%	Importance of conflicts	%	Main Causes of conflicts	%	Methods of resolution	%
Necessary	72	Very high	3	Social problems	8	Friendly	44
Tolerated	25	High	31	Land use	26	Traditional	54
Not-desirable	3	Low	58	Land pressure	66	Administrative	1
		No opinion	8			Prosecution	1
	100		100		100		100

Table 6.5 Perception of the importance of agriculture /pastoral conflicts and their locations

Integration of pastoralists	%	Frequency of conflicts with pastoralists	%	Location of conflicts in wet season	%	Reason for conflicts in dry season	%
Necessary	46	Negligible	3	Champs de case[1]	5	None	54
Tolerated	46	Few cases	31	Champs de brousse[2]	92	Watering	4
Not-wanted	8	Frequent	58	Orchards	1	Orchards	12
		Too frequent	8	Irrigation areas	0	Crop destruction	16
				Water points	2	Gardens	12
	100		100		100		100

1: Fields close to settlements; 2: Fields located outside the settlements (more than 1.5 km)

Table 6.6. Percentage of villages where past or recent severe conflicts occurred

	Past conflicts (% of villages)				Recent conflicts (% of villages)			
Existence of conflicts	Conf1	Conf2	Conf3	Conf4	Conf1	Conf2	Conf3	Conf4
No	96	96	46	98	98	90	42	92
Yes	4	4	54	2	2	10	58	8
	100	100	100	100	100	100	100	100

Conf1: natives/natives; Conf2: natives / immigrants Conf3: agriculture/ pastoral; conf4: village / village

Table 6.7 Perceptions of projections and possible solutions for conflicts

Projection of conflicts	%	Reason for increased conflicts	%	Type of solution to conflicts	%
More conflicts	76	Population pressure	69	Participatory land use planning	47
Same level	12	Land policy	2	Traditional tenure systems	8
Fewer conflicts	7	Land degradation	2	Strengthen policy instruments	18
No opinion	5	Traditional tenure	5	Suppress land reform law	1
		Cultural differences	6	Negotiation	14
		No opinion	13	Socio-economic welfare	10
				No opinion	2
Total	100		100		100

- *(5) Tools and mechanisms for local conflict management*

For 98% of the farmers interviewed, the modern laws (perceived as “administration”) have a little effect on the mechanisms used for conflict management at local level. 91% also admit that they do not rely on the regulations prescribed by land reform law. The reason usually given (69%) is that they do not understand these regulations because they have never been adequately explained to them. Therefore, they rely more on their traditional systems, which favour negotiation and peaceful agreement between individuals or groups. However, as Table 6.7 shows, participatory land use planning and community-based land management programmes constitute the best remedy for local conflicts according to the local people (nearly 50% of the responses). This preference appears to be even stronger if we consider that negotiation (14% of responses) and the improvement of the socio-economic welfare of local people (10% responses) are embedded in the participatory land management process.

6.3.3 Conflict analysis and risk mapping from PRA in the pilot project area

The group interviews revealed that, like in many other African countries, rights of access to land in the pilot project area stem initially from membership in the ethnic groups who first occupied the land. According to Stamm and Sawadogo (1995), each native group exerts within the boundaries of its cultural domain, the eminent domain rights of the first inhabitants, which are recognized by the surrounding communities. New settlers gain access to land through their links with members of these native groups. For instance, the immigrants and (some landless people within the native population) borrow land only for use for a limited period. All the villages, except the village of Maro, belong to five traditional domains, namely Kadomba, Bekuy, Fina, Balla and Tierako (see Figure 6.2). Different settlements, which started as cultivation hamlets, were later created, as the cultivable land became scarcer in the immediate surroundings of the old villages. Some settlements were also created by immigrants.

The PRA tools used in conflict analysis in the project area revealed the following situation:

- According to the national rules, settlements having at least a population of 600 people have a status of administrative village with the right to receive their own infrastructure: schools, health centres, technical services, etc. Moreover, they have statutory and legal rights to decision making in development planning, while in practice they have no customary rights regarding land issues. Even though no open conflict has yet occurred, this is sometimes a source of tension between villages.

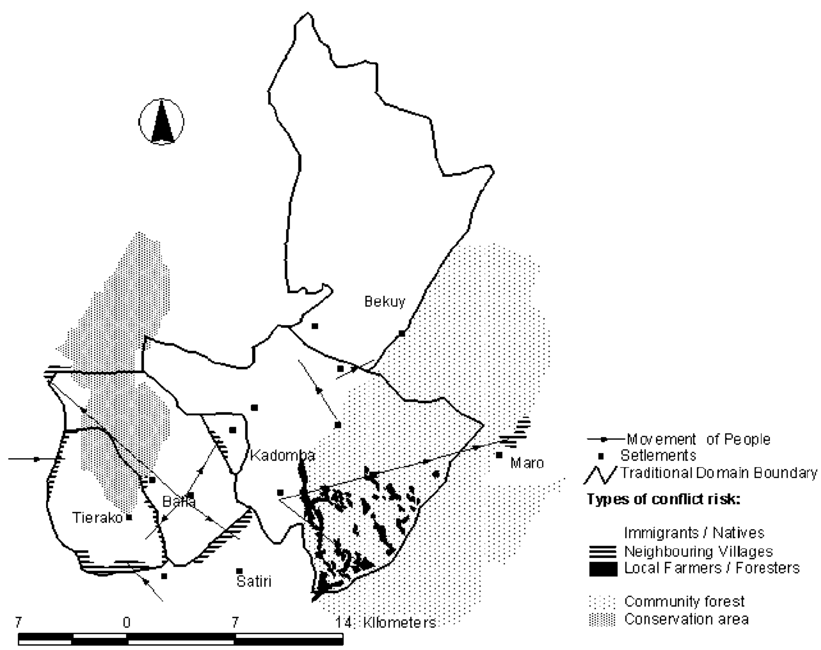


Figure 6.2 Location of conflict risk in the project area mapped with PRA tools

- The creation of the reserve areas has curtailed the initial size of the traditional domains, and disorganized the distribution of land between the lineages. Some lineages have been reallocated smaller portions of land. More importantly, others have even turned from the status of landowners in their villages to borrowers in neighbouring villages. The increasing demand for land has increasingly stimulated the landowners to reconsider these traditional agreements.
- The reserve areas preserve important resources, which are highly desired by many farmers (agricultural lands and pastures), and their exploitation is often a source of conflict with the foresters.

Figure 6.2 shows the different conflicts and conflict risk areas as revealed by the sketch maps, Venn diagrams and the preference matrices. The areas of conflict between local people and foresters were identified from photo interpretation with the help of local informants. Figure 6.3 shows the potential conflict areas derived from the pressure indices on agricultural and pastoral lands. In the absence of the actual total area of each village, the pressure indices on agricultural lands and rangelands were computed from the equations (1) and (2) using areas derived from a Thiessen polygon interpolation.

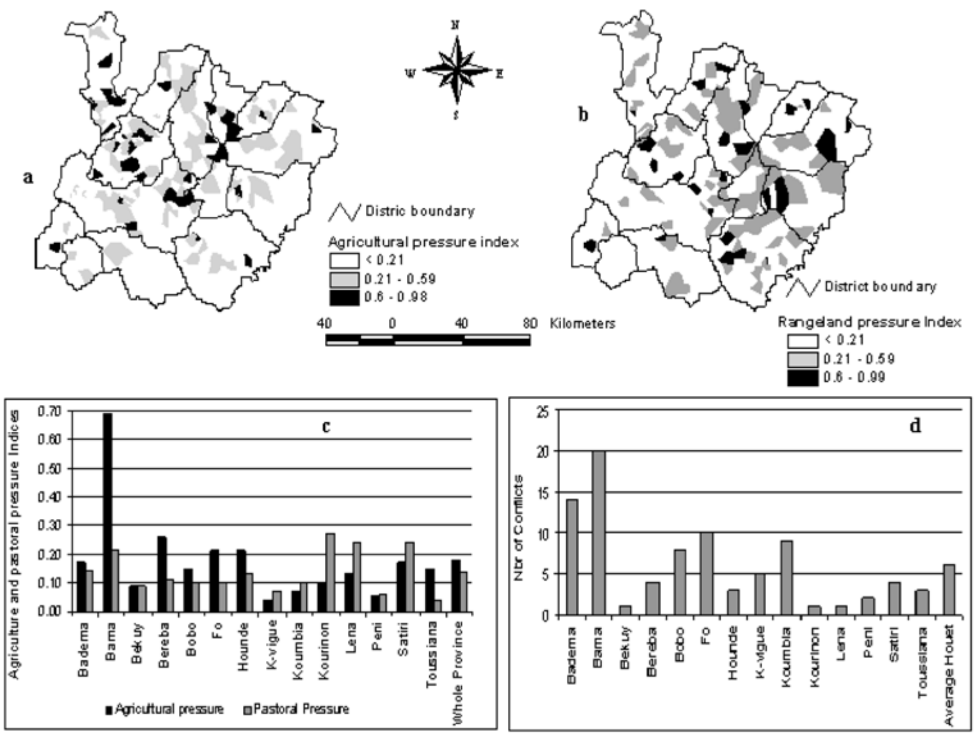


Figure 6.3 Conflict risk mapping. **Figure 6.3.a:** The conflict risk areas in agricultural lands based on pressure index on agricultural lands. **Figure 6.3.b:** The conflict risk areas on pastoral lands based on the rangelands pressure index. **Figure 6.3.c**: The average pressure indices at district and provincial levels. **Figure 6.3.d: T**he number of conflicts per district

Figure 6.3a and Figure 6.3b show respectively the maps of conflict risks on the agricultural lands and rangelands, based on a classification of the pressure indices. Figure 6.3c indicates the average agricultural and pastoral pressure indices aggregated at the level of each district and at provincial level. The general trend of the indices indicates that the pressure on agricultural lands is higher than the pressure on rangelands. This is also confirmed by the mean indices per district and at provincial level as indicated in Figure 6.3c. Figure 6.3d indicates the number of conflicts per district and the average number at provincial level. A visual observation shows some similarities between Figure 6.3c and Figure 6.3d, which indicates a possible correlation between the pressure indices on land and the intensity of conflicts. This observation is somewhat confirmed by the results of the multiple regression as shown in Table 6.8.

Table 6.8. Results of the multiple regression

	Beta	Partial Correlation	Coef B	R-square	p-level
PVMIG	0.404	0.61	0.072	0.083	0.045*
PRELAND	0.69	0.80	24.26	0.073	0.003*
PREPAST	-0.05	-0.089	-3.92	0.25	0.80
NONWAT	0.15	0.27	1.5	0.11	0.42
NONSERT	0.257	0.42	11.82	0.16	0.19

Predictors: (Constant = -11.42), NOSERT, PRELAND, PVMIG, NONWAT, PREPAST
Dependent Variable: NBRCONF; R = .869 R^2 = 0.755 Adjusted R^2 = .646 p-level = 0.08;
(*) = Variables with significant correlation. (α = 0.05)

The table indicates that the number of conflicts is significantly correlated to the pressure on agricultural lands (PRELAND) and the presence of immigrants (PVMIG), as shown in Figures 6.4a and 6.4b.

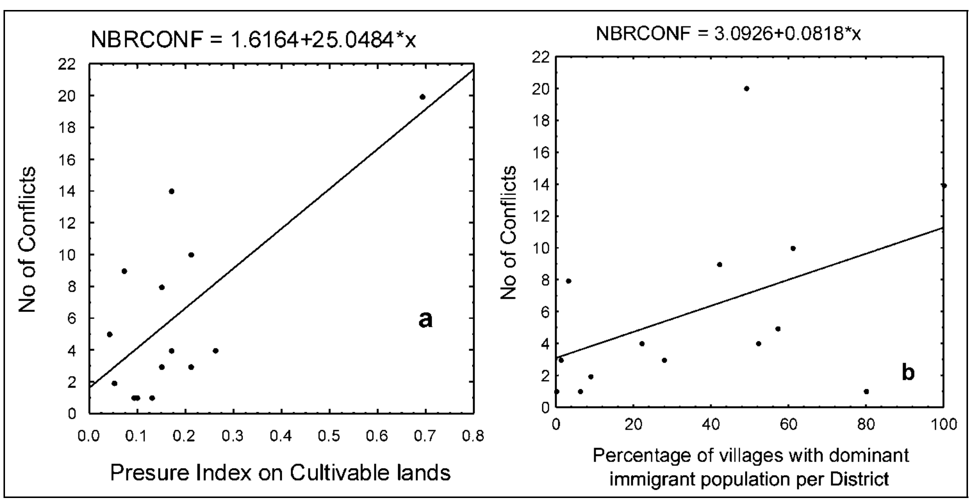


Figure 6.4: Scatter plot of the number of conflicts per district. **Figure 6.4a** shows a scatter plot of the number of conflicts according to the pressure index on agricultural lands. **Figure 6.4b** shows the scatter plot of the number of conflicts related to the percentage of villages of immigrants per district.

Even though the pressure on pastoral lands (variable PREPAST), the lack of water during the dry season (variable NONWAT) and weak institutional support (variable NONSERT) are not significantly correlated, they contributed to rising the general regression coefficient to a high level $R^2 = 0.755$.

6.4 Discussions

6.4.1 General perceptions on the issues of conflicts

The analysis of the interview data shows that the conflicts are localized and there is in general a willingness to control them with local (traditional) mechanisms. However, the increase in number and the shifts in the issues create important risks of escalation into uncontrolled situations. For instance, the district authorities have mentioned that conflicts between individuals are increasingly turning into violent inter-ethnic conflicts between natives and immigrants. An illustration was given in the district of Badema where many Mossi farmers where forced to move to the south of the Province (in the district of K-Vigue) because of land disputes. Frequent disputes over agricultural lands among the native population were also reported in the district of Banfora, because of the inextricable consequences of the traditional matriarchal regime of inheritance clashing with the increasing commercial value of the land. According to information obtained from the district authorities and local key informants, conflicts between farmers and pastoralists dominate in frequency in each location and are widely distributed over the province. The reason given by the pastoralists for being involved in frequent disputes is the shifting shape and increasing size of the agricultural holdings, while the farmers blame the pastoralists for the destruction of crops and yields. Although agriculture/pastoralism types of conflicts have always been part of the rural societies in West Africa (Guey, 1996), it must also be acknowledged that the perception of an increase in number and importance is not just an illusion generated by the growing literature on the issue (Blench, 1998). More importantly, many district authorities report that an increasing number of conflicting parties resort to violent solutions. For example, a case of bloody conflict between groups of farmers and pastoralists recently brought to court in the district of Banfora was transformed into a conflict between the traditional congregation of hunters and the Fulani ethnic group.

6.4.2 Analysis of the main factors of conflicts

The study shows that there is a strong perception among local people that population pressure is the main cause of conflicts. The results of the statistical analysis show an important absolute growth per district in 20 years, confirming the perceptions of the local people. This is an important indicator of the impact of population growth on the increasing demand for agricultural and pastoral lands during that period. Different investigations in the study area showed that this tremendous population increase is attributed to the significant immigration of farmers, mostly the ethnic group of Mossi from the central plateau of the country (Gray, 1999; Gray and Kevane, 2001; Pare, 1998). The distribution of population in the province shows that the proportion of villages composed primarily of immigrants is very high (Table 1). For example, this proportion for the districts of Bereba and Bekuy in the north of the province are respectively 100% and 80%.

Some authors argue that this process has been aided by the changes in the statutory land laws and national land policy (*Reorganisation Agraire et Fonciere*, 1984), which decreed that all land belongs to the state (Kote et al., 1998; Gray and Kevane, 2001). However, the increase in agricultural and pastoral lands is also explained by the growing interest in commercial farming, mostly cotton cultivation and investment in livestock. Between 1984 and 1999, the total area under cotton cultivation increased by 250% (from 207,810 ha to 717,410 ha) in the study area, while it increased 96% for maize and sorghum (from 73,384 ha to 143,796 ha). It can be noted that cereals are also increasingly converted into commercial crops. In all cases, this illustrates that it is not only the population pressure that has contributed to intensified competition between the stakeholders for living space.

Furthermore, the study illustrates that the rapid socio-cultural and demographic changes are important vectors of natural resource-related conflicts. As shown by the analysis of the interview data, the customary tenure systems based on the values of the ethnic groups that first occupied the land constitute the (legal) basis of land access and land rights for most villagers. These results also corroborate the findings of previous studies in the study area (Kote et al., 1998; Thieba et al., 1995; Sedogo and Groten, 2000). The important social changes in tenure and demography, together with an increasing shift toward a market orientation of the rural economy, have contributed to alter the traditional relationships between individuals and groups at village level. Indeed, it can be noted from Figure 6.5 that the population grew at a lower rate between 1985-1995 compared to the previous decade (1975-1985).

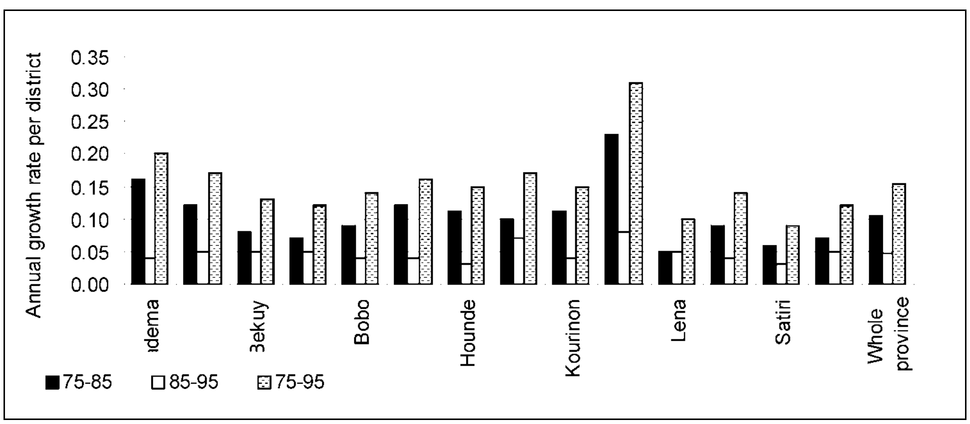


Figure 6.5. Population growth rate per district between 1975 and 1995

The elders of the native groups acknowledge that the immigration of Mossi farmers during the period 1975 -1985 positively contributed to social and economic improvement and political recognition of their villages.

However, the impact of the land reform law issued in 1984 (which in essence was to give equal land rights to everyone) and the severe droughts in central and northern Burkina Faso during 1983-1985 created a massive flow of new immigrants in the area. As a result, the welcoming attitude towards immigrants shifted towards frustration and rejection as the land became scarcer (Gray, 1999). Kote et al. (1995) mention a growing perception of insecurity among the native people due to an increasing real or perceived imbalance of power favourable to immigrants. Pare (1998) also noted from different case studies in the cotton belt in south-western Burkina Faso that some customary rules such as land borrowing have evolved to more precarious and short-term contracts between land owners and land seekers (including within the same clans, such as between uncles and nephews).

6.4.3 Methods of conflict mapping and prediction

The study shows that relevant information based on sketch mapping and diagrams can be extracted from PRA data for mapping potential conflict areas using a GIS. These results also confirm previous findings on the use of these PRA methods to clarify and understand conflicts (Conway, 1989; Chambers, 1994). Application of a ranking method to map potential land use conflicts in a village project based on farmers' preferences for different types of land units and resources was also illustrated by Sedogo and Groten (2000). However, in practice, the procedures of participatory mapping may also increase the danger of bringing latent conflicts to the surface, if the process is not well discussed and the objectives are not well understood by the stakeholders. In the present case, the participatory process of locating conflict areas on the ground was strongly rejected by the elders and project staff, to avoid creating a real conflict from an issue that was still kept under control by the local traditional systems. Instead, mapping potential conflict areas from GIS is less threatening and may help regional authorities to better organize the negotiations among the local stakeholders.

This study shows that the pressure index on agricultural land is a good indicator that can be used to map agricultural and pastoral conflict risk areas. Furthermore, the results of the multiple regression show that the importance of land use conflicts at district level can be significantly predicted using the following variables: the pressure indices on agricultural lands, the percentage of villages made up predominantly of immigrants (which affects the traditional tenure regimes), the availability of surface water, and the presence of technical services. With this result, the hypothesis was tested that the conflicts over resource use are a function of the competition for resources (due to population pressure), the insecurity in land rights, and the absence of authority (weak policy instruments).

The study also shows that beyond the popular narratives, population pressure is an important cause of conflicts. As such, this result strongly supports the local perceptions. Immigration, which is an important factor of population growth in the area, is also a strong contributing factor to conflict risk. However, the study suggests that the high frequency of agriculture/ pastoralism type of conflicts is not due to the extensive livestock farming as perceived by the farmers, but is mostly a result of the tremendous dynamic of agricultural land use, due to population pressure and commercial farming expansion.

6.5 Conclusion

Scope exists within the framework of participatory planning to undertake conflict analysis and mapping using socio-economic and remote sensing data linked with PRA tools and local people's perceptions. Such a procedure was used in the present study to identify the main conflicts faced by the rural people, the main factors contributing to the conflicts, and the areas at risk. The results of the study show that both interpretative and prescriptive analyses are important for conflict analysis in a participatory planning environment.

It was shown that the population increase and market farming, which create high pressure on agricultural lands and create insecurity over access to resources (changing statutory and customary land rights), are the main causes of the conflicts. Despite the relatively high frequency of disputes between farmers and pastoralists, the rapid expansion of agricultural lands was found to be the main source of conflicts at the local level. Linking PRA tools with other conventional data collection methods proved to be useful in mapping the conflict risk areas and strengthening GIS as a tool to support the participatory planning process.

CHAPITER VII

GENERAL DISCUSSIONS AND CONCLUSION

7.1 Introduction

With the introduction of the *Gestion des Terroirs* approach, convincing examples of rural development give hope that a start has been made to the sustainable development process. In many respects, it is believed that the approach is promising for the rural development actors such as the local communities, national and international institutions (UNSO, 1994; Capo-Chichi et al., 1995; Schorlemer, 1997). The introduction of geo-information technologies and remote sensing as local decision support tools (Groten, 1996; 1997; 1998) is promising for participatory land use planning. However, these positive expectations do not imply that the approach has been only successful up to now. Rather, many deficiencies still hamper its implementation (Engberg et al., 1993; Batterbury, 1998). For some problems adequate solutions have been found through research-development projects (Gueye and Schoonmaker-Freudenberger, 1991; Chambers, 1994a; 1994b; 1994c; Capo-chichi et al., 1995). Some solutions have also been sought through political, institutional and legal reforms in different countries (e.g. agrarian reform in Burkina Faso, decentralization in Mali and Burkina Faso, etc.).

Yet, pending issues were considered important enough to motivate the present research. For instance in the context of the *Gestion des Terroirs* approach, important questions are often raised about how PRA and GIS can be adequately linked. Answering these questions could certainly contribute to optimizing decision-making at the *terroir* level by emphasizing the wealth and diversity of local knowledge. It could also contribute to empowering local communities more in decision-making and planning for the sustainable management of their resources and, therefore, launch good governance from the bottom. Other important challenges relate to the problem of scaling-up from the *terroir* to higher levels (Abbot et al., 1998; Weiner et al., 2001). In other words, methods aiming at extending the positive outputs of the local participatory land management process to meso (e.g. project areas) and regional levels are also needed (Sombroek and Eger, 1997) in order to trigger the bottom-up land use planning process.

Therefore, the study aimed at developing methods for a rational integration of local participatory and regional planning for sustainable land management using geo-information tools.

Several steps were necessary to achieve these objectives, based on a case study of participatory land use planning implemented in the province of Houet in south-western Burkina Faso. In this chapter I discuss these different steps by reviewing the different objectives of the research and highlighting the main findings. The chapter uses a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) as a means of evaluating the different methods used in the study. It identifies their potential contributions to local participatory land use planning and discusses the implications for regional policy. Finally, it draws conclusions and formulates some recommendations for future research in order to improve the use of geo-information as a participatory land use planning decision-making tool.

7.2 Specific objective 1:

> "*To develop a method for defining and mapping the land management units relevant to all stakeholders and suitable for systematic storage in a GIS environment"*

In the context of the study, the major problems of linking participatory rural appraisal (PRA) with GIS were mainly caused by (a) the difference between the conception and representation of spatial phenomena by local communities and modern scientists (a mental versus a physical construct); (b) the difference in the nature and formats of the data used (soft and qualitative data at local level versus hard and quantitative data at regional level).

7.2.1 Linking PRA and GIS

The rationale of the method used in this study is that a GIS is first and foremost an information system, developed for the specific needs of addressing spatial issues.

- Firstly, the method allowed the best use of PRA tools for developing a spatial information system as a model of the *terroir* planning environment. A hybrid approach was used, which combined hard and soft system development methodologies. In a system development process, system analysts use the understanding of the existing system and its problems to design and build the new system. On the other hand, PRA methods put emphasis on high quality and relevant data and on the importance of building information in full collaboration with the local community, which is the information-holder (Chambers, 1994a; 1994b; 1994c). In the Kadomba village case study (Chapter 2), PRA tools were successfully used to interactively implement (with the local farmers) the *terroir* information system, suitable for a GIS environment. The diagramming tools and the sketch maps used by the local people made an important contribution to translating the local geographic concepts, entities and relationships (based on mental constructs) into a logical model. The interactive information system development was also a good learning process for the local people. It gave them a better understanding of their local planning environment by identifying the different components, their mutual interactions and information flows. Identification of the information gaps and the weaknesses of their traditional land management system allowed them to propose and adopt new land use strategies. For instance, the analysis of the interactions between the cropping systems and the livestock farming system led to the creation of a pastoral zone as a stable land management unit recognized by all the stakeholders. Therefore, PRA has fully demonstrated its ability to bridge the local knowledge system with a GIS environment, by providing the information required for conceptual and logical model development.

- Secondly, the method explored the direct use of PRA information in a physical model stored in a GIS. It used PRA information as the basis for a spatial analysis in a GIS to define the land management units relevant to all the stakeholders involved in the participatory land use planning in the *terroir* of Kadomba. A statistical analysis using rural rapid appraisal (RRA) survey data collected in the village showed that the local socio-cultural (i.e. tenure regimes) and economic constraints (field size, labour availability, number of cattle) are important driving factors in the participatory land use planning process. The study showed that it was possible to link PRA information related to the farmers' land use strategies (flood, erosion and conflict risk minimizing) with a terrain-units map and a slope map derived from a digital elevation model (DEM) of the area, to derive potential agricultural land management units. The overlay of this data layer with the agricultural units mapped from photo interpretation gave a strong correlation of more than 90% ($R^2 = 0.92$). Similarly (in Chapter 3), a spatial analysis involving (a) the pastoral zone created by the participatory land use planning at the *Programme National de Gestion des Terroirs* (PNGT)-project level in the study area, and (b) the terrain-units map created from DEM was performed. The pastoral zone matched with 80% accuracy the lands the farmers were not interested in for crop growing. Therefore, with the PRA information related to the local biophysical knowledge, it was possible to identify and map with the GIS the agricultural and pastoral lands, matching reasonably with the perception of the local farmers. It was also possible to use different factors derived from participatory planning policies and regulations (also from PRA tools) to map with the GIS feasible forestry and environmental land management units. Therefore, the study showed that there is room for operationally using local knowledge in a spatial analysis that contributes to reliably linking PRA and GIS. This approach is efficient for supporting the local land use planning process, as it is based on available tools (PRA tools, air photos and a topographic map for building the DEM). In agreement with Abbot et al (1998), participatory GIS draws on the diversity of experiences associated with participatory development and it involves communities in the production of GIS data and spatial decision-making.

7.3 Specific objective 2:

> *"Develop methods for integrating local knowledge and regional planning information for bottom-up regional planning purposes, using GIS and expert systems."*

7.3.1 Linking the terroir and the regional levels: A spatial approach

The type of integration considered in this thesis was not a simple aggregation procedure, consisting of scaling-up from the *terroir* to the regional level using a mathematical model. The integration procedure aimed to provide a mutual support to both levels in order to ensure an efficient use of available resources. In both directions, a key issue was "information flagging" aiming to avoid distorting (or even eliminating) important information during the upward or downward flow processes. The bi-directional approach proposed in the study allowed for a spatial transformation of the information issued at one level to serve as input at the other level. A spatial abstraction using the *terroir* as the basic entity aggregated the local participatory information at the regional level. PRA data collected in 17 pilot villages determined the main factors impeding implementation of local participatory land use plans at a regional scale.

With the implementation of the approach (in Chapter 3) a new pastoral zone that was socially acceptable by the all stakeholders and ecologically sustainable at the pilot project area level was identified. Based on the same procedure, information extracted from PRA tools (tenure regimes, labour shortage and time constraints) was used as aggregation factors to map at a regional level the areas where more support for the implementation of participatory land management activities is needed. Similarly in the downward direction, the areas where the impact of regional activities might have negative consequences on the implementation of local participatory plans were identified. Therefore, the spatial aggregation procedure harmoniously linked these two planning levels and made it possible to generate important decision-support information at the regional level, based on local planning information.

7.3.2 Integration of local knowledge into regional planning: a knowledge-based GIS approach

An expert system was proposed (in Chapter 4) as a means of integrating the local perceptions and knowledge into regional planning information. Using Bayesian probability rules, the expert system successfully combined local knowledge together with regional biophysical and socio-economic GIS data layers to classify land degradation areas at regional level.

From a technical perspective the evaluation of participatory land degradation mapping data collected in an independent sample set of 50 villages gave very satisfactory results compared to a conventional GIS method. This shows that the expert system bridged the gap and connected the biophysical factors (using remote sensing) to the socio-cultural and economic perceptions of the local people.

From a planning perspective the ranking procedure used to build the expert system was useful for checking the relevance of previous participatory diagnosis. The perceptions of the local people were used to weigh the importance of each parameter in the overall state of land degradation in each village. Contrary to prevailing opinion in the area (Gray, 1999), the study did not find an association between high land degradation and an increased presence of immigrants. Similarly, no association was found between high land degradation and high population and cattle densities. On the other hand, it showed that the low degraded lands corresponded to village territories where farmers are implementing land reclamation and land management activities based on the *Gestion des Terroirs* approach.

These results show that an expert system can supply the regional policy-makers with critical and relevant planning information, reflecting the views and perceptions of local people from the *terroir* level.

7.4 Specific objective 3:

> *"To develop methods for addressing critical issues in sustainable land management, such as land degradation assessment and conflict management, at regional level using both local knowledge and regional planning information."*

7.4.1 Exploring the degradation of local land management systems from a regional perspective

So far, no convincing attempt has been made to predict the potential impacts of local participatory land use planning at larger scales, nor to evaluate its consequences from a regional perspective. However, such an exercise could help to valorize initiatives and actions at the bottom-level of the *terroir.* It could also help to enhance the contributions expected from the top (meso or regional levels) in supporting bottom-up planning processes. In this study, the expert system allowed us to evaluate the state of degradation of the local land management systems at a regional scale, based on local perceptions. The study compared the output of the expert system with the outputs of a nutrient budget model and a vegetation trend-mapping model. It showed that the expert system agreed better with PRA assessments than the two other models. The expert system also explored the impact of different local land management scenarios on the global status of land degradation at the regional level. The following scenarios were considered: (i) agricultural development; (ii) environmental conservation; (iii) household income raising; (iv) social development; (v) and erosion control considering only biophysical parameters.

The study showed that the scenario for environmental conservation best reflected the actual situation of land degradation as perceived by the local population. This suggested that farmers' perceptions on land degradation are mostly influenced by environmental considerations. The rural population in Burkina Faso is very much aware of environmental problems, especially desertification. The scenarios of increasing agricultural production and increasing household revenues predicted a deteriorating situation for land degradation, giving a very low proportion of low degradation areas and an important proportion of high degradation areas (more than one third of the province). This calls for agricultural policy improvement in order to stimulate more land management activities such as: a fertilization policy to increase agricultural intensification, a farmers' crop products pricing policy to increase household income, etc. The good status of land degradation predicted by the scenario of erosion control (involving only biophysical parameters) reflected certainly the relative wealth of the natural resources in the province as perceived by the farmers: generally good soil, abundant vegetation, considerable rainfall and moderate slopes. The worst situation was depicted with the scenario of promoting social welfare, which predicted that the highest degradation areas would cover nearly half of the area. This result calls for the implementation of integrated approaches in rural development (including environmental components) to the detriment of sectoral socio-economic development programmes.

The study showed that the expert system could be used as a simulation model that could help support planning and policy analysis at the regional level. This also demonstrated the ability of the expert system to aggregate local participatory land use planning information at a regional level, contributing to bottom-up regional planning.

7.4.2 Linking PRA and GIS for conflict risk mapping in bottom-up planning

In the *Gestion des Terroirs* approach, conflicts may easily arise (FAO, 1995; Sombroek and Eger, 1997). Mechanisms predicting the location and scale of potential land use conflicts should accompany the planning process in order to improve negotiation between the stakeholders. The approach used in this study determined the main causal and predictive factors of conflicts on resource use in the study area, based on both interpretative and prescriptive analysis. Stakeholder analysis, PRA and RRA surveys identified the main conflicts and their causes in the study area.

The study showed that in general the conflicts have a local scale and the local people were more willing to control them with their traditional mechanisms than with other means. They perceived population pressure as the main factor contributing to the conflicts over the use of the natural resources. Market farming was also identified as an important cause of conflict. There is intense pressure on agricultural lands and insecurity over access to resources (changing statutory and customary land rights). The analysis showed that the rapid expansion of agricultural lands was a major reason for the relatively high frequency of disputes between farmers and pastoralists at local level. The study showed that PRA tools were relevant for mapping conflict risk areas at local level.

However, the participatory mapping should also consider the risk of bringing latent conflicts into the open. The predictive factors of conflict risk derived from the questionnaire data created a conflict risk index on agricultural lands and a conflict risk index on pastoral lands. These indices made it possible to map the potential areas at risk of conflict at a regional scale, showing that PRA socio-economic and remote sensing data can be linked with GIS to predict conflict risk areas relative to agricultural or pastoral farming practices. The multiple regression showed that the importance of land use conflicts at district level was significantly correlated to the pressure index on agricultural lands, the percentage of immigrants (which affects the traditional tenure regimes), the availability of surface water, and the presence of technical services as predictive variables. The correlation with the pressure index on pastoral lands was not significant. With these results, the hypothesis was tested that the importance of conflicts over the use of natural resources is a function of competition for resources (due to population pressure), insecurity in land rights, and the absence of authority (weak policy instruments). These variables are good indicators of land use conflicts in the study area. They can be used to orient policy-making at regional level, especially for increasing the protection of the pastoralists and giving more support to livestock farming by generalizing the creation of stable pastoral zones where possible. They could also be used to stimulate a better immigration policy in order to improve sustainable land management in the area.

7.5 Evaluation of the methods used in the study: a SWOT analysis

From the above presentation of the main findings, it is clear that the methods used in the study have made it possible to answer the key questions that motivated the research. A SWOT analysis was applied as a means of organizing the analysis and discussions based on an evaluation of the methods used, both in terms of scientific relevance and usefulness and effectiveness in the participatory land use planning in Burkina Faso.

7.5.1 Strengths

From a scientific point of view, the study answered important questions in the participatory GIS research agenda. For instance, Abbot et al (1998) raised the issue of how local knowledge can be integrated with, and represented in, an information system, which by definition has traditionally rejected such knowledge in favour of spatially defined "expert" information. The hybrid system development methodology proposed in the study gave a good answer to this question. It offered the advantage of effectively merging indigenous knowledge with the outsiders' expertise and scientific skills. This allowed development of an integrated information system capable of handling land use and land management issues as perceived by both local people and development partners.

The problem of linking PRA and GIS was also raised in many circumstances as an important step in building participatory GIS (Abbot et al, 1998; Carver, 2001; Weiner et al, 2001). The methods proposed in the study are tangible examples of responses to this concern:

- The system development methodology emphasized the role of PRA as a relevant information provider for a geographic information system. With the holistic system approach applied in the context of the *Gestion des Terroirs*, the local people themselves emphasized PRA as an important tool. It expressed and enhanced the local knowledge necessary to build an information system. After geo-referencing, PRA data can be reliably used in GIS spatial analysis to address local land use issues.

- With the geo-information procedure proposed in the study, PRA data can be used in GIS analysis. This method is a rational basis to support bottom-up land use planning.

- The Bayesian implementation of the expert system is an operational use of local knowledge for building a knowledge-based GIS. The use of probability rules for local knowledge representation proved to be useful and relevant for linking qualitative (PRA) and quantitative data. The facilities offered by the spatial database of GIS (storage, updating, easy retrieval and analysis of the information) reduces the drawbacks of the method, such as the high level of generalization that takes place from village to regional level. For instance, more detailed analysis involving local spatial information (also stored in the GIS) and the evidence layers can compensate for the limitations of the coarse assessment of land degradation at the regional scale. This approach of linking PRA information and GIS from a knowledge-based system perspective is an innovative and promising way to build participatory GIS.

- The conflict analysis showed that PRA, socio-economic and remote sensing data can be linked with GIS to predict the location and the spatial scale of land use conflicts.
- Finally, the approach reinforced the credibility of PRA as an operational tool in land use planning and sustainable natural resources management data gathering strategies.

From a participatory land use planning perspective, it is clear that the approach allows the real expression of the local land use problems by the local people themselves.

- The system development methodology using PRA tools offers them the possibility of better structuring land use problems according to the (socio-cultural, economic and ecologic) components of their local land use system and to identify the interactions between them. With this systems approach, the functional weaknesses and gaps in the traditional land management system are more visible for the decision-makers. This could stimulate remedies (in both conceptual and operational forms) better oriented to the satisfaction of the users' (local and regional stakeholders) needs. The process of creating a new pastoral zone in Kadomba is a good illustration of this.

- The approach used for building the expert system interactively with the local people (identification of the variables used to create the GIS layers based on local indicators, building the probability matrices, validation through participatory mapping) is also a way of cross-checking the information obtained during the initial participatory diagnosis. For instance, the method of discussing and structuring the different evidence layers with the local farmers reinforced their knowledge about land degradation. They could better understand not only the individual impact of the different factors, but also the impact of the phenomenon in its global form. The construction of the probability matrices allowed the identification of the major factors contributing to land degradation, which can be used for better strategy design. As shown with the example in the district of Banfora, this allowed the identification of soil acidity as the foremost concern of the local farmers rather than soil erosion. Because of this emphasis, the erosion control implemented in the framework of their local plan was not successful despite the considerable amount of funds allocated for this by the PNGT project.

- The method of linking PRA, socio-economic and remote sensing data with GIS to predict and map the existing and potential land use conflicts is an important tool for conflict management and for participatory land use planning. By revealing at the regional scale the main factors leading to conflicts according to the perception of the local farmers, local and regional views about the issue are harmonized. As such, it also contributes to better linking and integration of these two levels.

- The approach of building the participatory GIS is a challenge for all the stakeholders involved in the participatory planning process to be the real constructors of the GIS (as main information providers and system analysts). Under these conditions, GIS is likely to remain a participatory tool.

- Finally, for successful implementation of the *Gestion des Terroirs* approach nation-wide, the PNGT programme needs a tool that provides not only adequate support for the development of the local land use plans, but also merges them into harmonious regional frameworks. The approach and methods used offer the opportunity to fulfil this need. Therefore, this study could be an important contribution to the success of the programme.

Apart from the construction of the expert system, all methods and materials used are quite practical; hence the approach is reasonably feasible from a technical perspective for the PNGT programme.

7.5.2 Weaknesses

The hybrid system methodology used (hard and soft) makes it by nature vulnerable to criticism from both sides. For instance, practitioners of hard approaches could find that the inclusion of soft qualitative methods (PRA) in an approach aiming at sustainable natural resources management makes it superficial, not really allowing in-depth analysis and sophisticated modelling.

- The qualitative methods (based on farmers' perceptions) used for building and validating the expert system could be a good illustration. The qualitative information often includes a certain degree of subjectivity, which could indeed affect the end results. In a more general way, this poses the problem of the validity of local knowledge in scientific methods. To overcome this obstacle, different methods are used in participatory approaches to crosscheck the information collected using different sources (i.e. triangulation was used during the participatory surveys to minimize bias). In the particular context of land degradation assessment, the information obtained with the planning village committees was checked (when necessary) with the villages'native elders who have good historical background knowledge of the dynamic of the natural resources.

- The three classes used to evaluate the land degradation (low, moderate, high) could be sources of bias because of too optimistic views of the farmers (high degradation may be considered as moderate) or too pessimistic (low degradation may also be considered as moderate). In both cases, the moderate land degradation may be the dominant class. The generalization in three classes is therefore a limiting factor especially when the class of moderate is very dominant in the present case. It is a limiting factor for sharply analysing the results in order to draw critical conclusions and orient policy-making. Yet, using more classes to evaluate the level of land degradation (i.e. five classes instead of three) may not improve the end result, because of more subjectivity in separating different classes (e.g. very low and low).

- The use of quantitative data (probability matrices) for representing quality information (perceptions of the local farmers) could be negatively interpreted from a social science perspective, even though quantitative tools such as scoring techniques are widely used in PRA methods by the local people.

- For the participatory planning process, the consideration of the *terroir* as the basic planning unit is also a limiting factor. It could prevent the full expression and good representation of specific land use problems perceived by the less powerful groups (mainly the pastoralists and the women), despite the use of PRA. Therefore, incomplete information could be used for building the information system, portraying a partial view of the reality of the local land use problems.

- Finally, for many reasons (technical, organizational, infrastructure, etc.), an operational use of GIS is not feasible at the local level, but rather at higher levels (project area, regional). In this case, a participatory GIS built upon PRA could be criticized as being mostly extractive, contributing very little (if at all) to empowerment of the local people in the decision-making process and therefore, not enabling them to effectively influence policy-making.

7.5.3 Opportunities

Despite the points mentioned above, the medium and long-term opportunities that may be found in the methods proposed by the study are quite significant. The introduction and development of GIS are not to the detriment of the other methods used to support the participatory planning process. On the contrary, in the socio-economic context of Burkina Faso, the approach of developing a GIS based on tools and methods that proved to be efficient is a rational and feasible way of promoting participatory GIS as a tool to support the participatory planning process. Moreover, improving the efficiency of these tools and methods could enhance the contribution of participatory GIS to the participatory planning process. For instance, the use of the PRA method can be improved, new planning tools can be introduced (e.g. decision support models), biophysical and socio-economic data collection techniques can be improved together with the development of other participatory survey methods. The implementation of the *Gestion des Terroirs* approach started at a national scale in Burkina Faso and will also continue to fill important gaps existing at this scale. This concerns mainly the data availability (spatial data such as the boundaries of all village territories, more detailed biophysical inventories such as soil and vegetation, etc.). The government has started establishing a link between the *Gestion des Terroirs* approach and the decentralization process. This will certainly contribute to further empowerment of the local communities. There is no doubt that in this new context greater accountability is expected from participatory GIS, and there is hope that the technocratic and institutional barriers existing now around GIS will be lowered.

7.5.4 Threats

The interesting perspectives mentioned above do not disregard the existence of serious threats to the applicability of the approach proposed by the study. For instance, important questions related to the cost effectiveness and technical feasibility can be raised about the methods in the particular (socio-economic and political) context of land use planning in Burkina Faso. A cost-effective implementation of the approach could only be reasonably considered in the long-term if we include all the tangible and non-tangible benefits for the local people. More importantly, the methods and techniques used to build the expert system involve a very high level of expertise (i.e. programming skills) that may not be necessarily always available. To overcome this difficulty it is necessary to build a user-friendly interface to allow the best possible use by the regional GIS analysts.

Another threat is that the local people could lose control over their information. The danger already exists of PRA information being controlled by a small group in the community. This danger could be increased when linking PRA with a GIS because the information will be in reality only handled by the GIS experts. Therefore, the information could be more exposed to a seizure at the regional level, and the "participatory GIS" could remain a technocratic tool. This could be a step backward to a more top-down procedure. Therefore, mechanisms and tools (e.g. legal, political or administrative frameworks, more visualization tools such as participatory three-dimensional maps) are needed for better protection of the local information. This could guarantee that the participatory GIS will effectively contribute to legitimizing the local knowledge and empower the local people more in the decision and policy-making process.

7.6 Conclusions and recommendations

Based on the discussions above, I can conclude that the general objective of developing methods for a rational integration of local participatory and regional planning for sustainable land management using geo-information tools targeted by the study has been achieved. More specifically the methods developed in the study have made it possible to:

- Define and map the land management units that are relevant to all stakeholders involved in a participatory land use planning and suitable for systematic storage in a GIS, using PRA information;
- Integrate local knowledge and regional planning information for bottom-up regional planning purposes, using a GIS aggregation procedure and an expert system.
- Map land degradation at a regional scale based on local farmers' perception, and evaluate the potential impact of land use scenarios on the sustainability of the local land management systems using an expert system.
- Link PRA, socio-economic and remote sensing data with GIS for mapping at meso and regional level the potential areas at risks of conflict.

Although the study gave answers to some of the issues raised in the ongoing debate about participatory GIS (Abbot et al., 1998; Obermeyer, 1999; Carver, 2002; Weiner, 2002), the following points may be suggested as a direction for further research:

- In the participatory planning context of the *terroir*, the cultivators have greater decision-making power, so the greatest emphasis is on land management activities aiming to improve the cropping systems. Research that gives more consideration to the views and perceptions of the pastoralists and their understanding of the spatial aspects of decision problems could help to improve the *Gestion des Terroirs approach;*
- Further research is also recommended in knowledge representation for constructing a knowledge-based GIS, as it was revealed to be a promising approach for building participatory GIS as a tool to support participatory land use planning.
- Finally, research on cost effectiveness of participatory GIS is recommended in order to evaluate its feasibility in developing countries.

SUMMARY

SUMMARY

With the introduction of participatory approaches in development programs, it has become essential for planners to build and implement land use strategies based on the objectives, perceptions and knowledge of local people. Despite the richness of participatory rural appraisal (PRA) information used in the planning process, efficient geographic information gathering and relevant spatial analytical tools necessary to support the negotiation among the stakeholders are lacking. Besides, methods are needed to allow a harmonious integration between the local participatory and regional planning, so as to impulse a bottom land use planning process.

It was the aim of this study to develop a method for a rational integration of local participatory land use planning and regional planning for sustainable resources management. It combined participatory land use planning methods based on participatory rural appraisal (PRA), with technical methods using geographic information system (GIS) and remote sensing. It was based on a case study of a participatory land use planning implemented in the province of Houet in South-western Burkina Faso.

Chapter 1 gives a general introduction to the thesis. It analyses the foundations and context of participatory land use planning in Burkina Faso, and formulates the motivation, objectives and scope of the research.

Chapter 2 investigates a method contributing at linking PRA and GIS. Information collected through participatory surveys was used as GIS input for spatial analysis in a village land use planning. For this, the main factors determining the definition of the land management units relevant to all the stakeholders involved the participatory land use planning were identified and discussed. The chapter analyses the relevance of these factors for mapping the management units with a GIS. PRA data was used to understand land use strategies and identify the different factors influencing the definition of the local management units for further analysis in the GIS.

Chapter 3 develops a spatial approach for integrating local participatory land management information into regional planning, contributing to a bottom-up approach to land use planning. For coherently linking these two levels of planning a bi-directional approach has been proposed. It was capable of operating a spatial transformation of the information issued at one level, to serve as input at the other level. It was based on principles of geo-data abstraction procedure developed in spatial data handling theory. With such procedure, it was possible to determine the impact of different socio-cultural and economic factors (tenure regimes, labor shortage and time constraints) on the implementation of land management activities using PRA tools. Similarly in the downward way, it was possible to identify the areas where the impact of regional activities might have a negative impact on the implementation of local planning processes.

Chapter 4 proposes an expert system as a mean of integrating the local perceptions and knowledge in order to map land degradation at a regional scale. The expert system combined the knowledge of local people (used as expert knowledge) together with

biophysical, socio-economical and cultural data organized as GIS layers to classify land degradation areas at regional level using Bayesian probability rules. To validate the expert system, the *a priori* probabilities used to build the expert rule were determined with the villager during PRA surveys conducted in sample villages. An accuracy test of the expert system using participatory ground truth mapping data collected in an independent sample set of 50 villages, gave an overall accuracy of 82%.

Chapter 5 evaluates the state of the degradation of the local villages territories from a regional perspective. The map produced by the expert system was compared with maps created by a nutrient balance model and a vegetation trend mapping model using NOAA satellite image data. The expert system was used to develop different scenarios allowing to predict different figures of land degradation. These scenarios were based on the objectives determined by the local farmers in the framework of their participatory land use plans. According to the results, the scenario of environmental conservation reflected better the state of land degradation as perceived by the local population.

Chapter 6 Links PRA and GIS for conflict risk mapping in bottom-up land use planning. In this chapter an approach for determining the main causal and predictive factors of conflicts in the study area, based on both interpretative and prescriptive analyses, is was proposed. It used a stakeholder analysis to identify the main stakeholders and their interests, which served as basis for proposing a typology of the main conflicts using multiple keys. The conflicts as perceived by the local people were examined to derive the main causes using Participatory Rural Appraisal (PRA) and questionnaire data. The study showed that the local population perceived the population pressure as the main cause of the conflict over the use of the natural resources This factor was used to create a conflict risk index on agricultural lands and a conflict risk index on pastoral lands, which were used to map the potential areas at risk of conflict at a regional scale. A regression model was run, allowing testing the hypothesis that: conflicts are functions of the competition (for land), the insecurity in land rights, and the absence of authority (weak institutional representation and policy instruments).

Finally the thesis uses a SWOT analysis (Strength, Weaknesses, Opportunities and Threats) as a means of evaluating the different methods developed in the study. It derives the potential contributions to local participatory land use planning and draw the implications for regional policy and planning. In many aspects, the study gave answers to some important conceptual and methodological questions in the participatory GIS research agenda, such as how to link PRA and GIS. The hybrid system development methodology used in the study offered the advantage of really merging together indigenous knowledge with outsiders' expertise and scientific skills It allowed to develop an information system capable of handling land use and land management issues as perceived by both local and development partners. In this respect the approach and methods used in the study could be an important contribution to the success of the *Programme National de Gestion des Terroirs* (PNGT) in Burkina Faso, by providing a framework for a harmonious integration between the local participatory and regional levels of planning.

SAMENVATTING

Met de introductie van participatieve onderzoeksmethoden in ontwikkeling programma's is het voor 'planners' essentieel om op basis van doelstellingen, denkbeelden en kennis van de lokale bevolking zelf, landgebruikstrategieën te ontwikkelen en te implementeren. Ondanks de rijkdom aan informatie afkomstig van participatieve onderzoeksmethoden ('*PRA')* die worden toegepast in het planningsproces is er een tekort aan methodes voor het efficiënt verzamelen van geografische informatie en voor ruimtelijke analyse door middel van een geografisch informatiesysteem (GIS). Deze gegevens en analyses zijn nodig voor het ondersteunen van onderhandelingen tussen de belanghebbenden. Bovendien is er een behoefte aan methodes die lokale participatieve planning en regionale planning op een harmonieuze wijze met elkaar integreren. Op deze wijze wordt gedecentraliseerde planning van onderop (een 'bottom-up' benadering)gestimuleerd.

Dit onderzoek heeft op basis van geoinformatica een methode ontwikkeld voor het effectief integreren van lokale participatieve landgebruiksplanning en regionale planning ten behoeve van het duurzaam beheren van natuurlijke hulpbronnen. Hierbij is gebruik gemaakt van een casestudie. Deze casestudie betreft de implementatie van een participatief landgebruiksplanning project op provincie- en dorpsniveau in het Zuidwesten van Burkina Faso.

Hoofdstuk 1 introduceert het onderwerp van het proefschrift. Hier worden de beginselen en de context van participatieve landgebruiksplanning in Burkina Faso geanalyseerd en worden motivatie, doelstellingen en het belang van het onderzoek omschreven.

Hoofdstuk 2 betreft een onderzoek naar een methode die bijdraagt aan het koppelen van PRA en GIS op dorpsniveau. Hierbij is informatie, verzameld aan de hand van participatief onderzoek, gebruikt als GIS 'input' voor de ruimtelijke analyses en landgebruiksplanning. Hiervoor zijn de voornaamste factoren die bepalend zijn voor de definitie van functionele lokale beheerseenheden ('land management units) die van belang zijn voor alle belanghebbenden betrokken bij participatieve landgebruiksplanning geïdentificeerd en besproken. In dit hoofdstuk wordt de relevantie van deze factoren voor het in kaart brengen van deze ruimtelijke beheerseenheden aangegeven. PRA data worden gebruikt voor het begrijpen van lokale landgebruik strategieën en het identificeren van verschillende relevante factoren ten behoeve van verdere analyse in GIS.

In Hoofdstuk 3 wordt een ruimtelijke benadering gepresenteerd voor het integreren van informatie afkomstig uit lokaal participatief landgebruiksmanagement met regionale planning op provincieniveau, en wordt zo een bijdrage geleverd aan een 'bottom-up' benadering voor landgebruiksplanning. Voor een coherente koppeling tussen deze twee planningsniveaus is een interactieve benadering gekozen die op het ene niveau in staat is ruimtelijke transformaties uit te voeren en evenals gegevens voor het andere niveau dient. Deze methode is gebaseerd op 'geo-data abstraction', afkomstig uit de 'spatial data handling theory'. Met een dergelijke procedure is het mogelijk het effect te bepalen van

verscheidene sociaal-culturele en economische factoren (eigendomsrechten, arbeidstekorten en tijdslimieten) op de implementatie van landinrichtings- en beheersactiviteiten. Op een gelijksoortige wijze is het mogelijk die gebieden te identificeren waarbij de implementatie van het lokale planningsproces een negatief effect heeft.

Hoofdstuk 4 stelt het gebruik van een 'expert' systeem' voor als een middel voor het integreren van lokale denkbeelden en kennis omtrent land degradatie op regionaal niveau in kaart te brengen. Hierbij wordt kennis van de lokale bevolking (gebruikt als lokale deskundigen) samen met biologisch-fysieke, sociaal-economische en culturele data in een GIS bijeengebracht. De data zijn georganiseerd in GIS lagen waarbij land degradatie gebieden via waarschijnlijkheidsregels ('Bayesian probability rules') geclassificeerd worden. Het 'expert' systeem' is gevalideerd door vanuit een steekproef van dorpen '*a priori* probablilities' vast te stellen, die gebruikt zijn voor het vaststellen van logische beslisregels ('expert rule basing'). Een nauwkeurigheidstest van het 'expert' systeem, uitgevoerd op basis van data afkomstig uit een onafhankelijke steekproef van 50 dorpen, gaf een overeenstemming van 82% t.o.v. de voorspelling. De data voor de validatie werden met behulp van zijn met behulp van participatieve inventarisatie verzameld.

In hoofdstuk 5 wordt de mate van degradatie van lokale dorpsterritoria vanuit een regionale invalshoek onderzocht. Er is een vergelijking gemaakt tussen de met het 'expert' systeem geproduceerde kaart en kaarten gecreëerd met behulp van een nutriëntenbalans en een GIS-model van vegetatieverandering, waarbij gebruikt werd gemaakt van in het land beschikbare satellietgegevens (NOAA NDVI data). Het 'expert systeem' is gebruikt voor het berekenen van verschillende scenario's, die ieder een voorspelling van de mate van landdegradatie geven. De scenario's zijn gebaseerd op de verschillende doelen die door lokale boeren binnen de participatieve landgebruiksplannen werden vastgesteld.

In hoofdstuk 6 zijn PRA en GIS aan elkaar gekoppeld voor het in kaart brengen van conflict risico's in het kader van 'bottom-up' landgebruiksplanning. In dit hoofdstuk wordt een benadering voorgesteld voor het vaststellen van primair-causale en voorspellende factoren met betrekking tot conflicten in het studiegebied. De benadering is gebaseerd op zowel 'interpretative' als 'prescriptive' analyses. Er is gebruik gemaakt van een analyse van belangengroeperingen voor het identificeren van de belangrijkste actoren en hun belangen. Deze analyse heeft als basis gediend voor het opstellen van een typologie van de belangrijkste factoren waarbij gebruik is gemaakt van 'multiple keys' in de data base. De belangrijkste oorzaken van de door de lokale bevolking waargenomen conflicten zijn vervolgens met behulp van PRA en enquêtes achterhaald. Het onderzoek toonde aan dat de lokale bevolking de bevolkingsdruk als de belangrijkste oorzaak zag voor het conflict over het gebruik van natuurlijke hulpbronnen. Deze factor is gebruikt voor het samenstellen van een conflict risico index voor zowel agrarische als pastorale gebieden. Deze indices zijn vervolgens gebruikt voor het in kaart brengen van gebieden waar zich eventueel conflicten op regionale schaal zouden kunnen voordoen. Vervolgens is een regressie-model toegepast waarbij de volgende hypothese werd getest: conflicten zijn functies van concurrentie (om land), de onzekerheid van landrechten en de afwezigheid van een duidelijk bewind (zwakke institutionele vertegenwoordiging en beleidsinstrumentarium).

Tot slot is voor een evaluatie van de in het onderzoek ontwikkelde methodes gebruik gemaakt van een sterkte - zwakte analyse. Met behulp van deze analyse werd per methode beoordeeld wat de potentiële bijdrage van de methode voor lokale participatieve landgebruiksplanning was en zijn er conclusies getrokken met betrekking tot de gevolgen voor regionaal beleid en regionale planning. Het onderzoek heeft op velerlei vlakken antwoord gegeven op belangrijke vragen uit het participatief GIS onderzoeksprogramma. De in het onderzoek ontwikkelde methodiek voor de hybride intergratie van verschillende systemen biedt het voordeel van het daadwerkelijk samensmelten van lokale kennis met kennis van buitenstaanders en van wetenschappelijke disciplines. Er is een informatie systeem ontwikkeld dat in staat is vraagstukken met betrekking tot zowel landgebruik and landbeheer te benaderen vanuit zowel een lokaal als regionaal ontwikkelingsperspectief. De in het onderzoek gebruikte benadering en methoden kunnen zo een belangrijke bijdrage leveren aan het succes van het nationale voor lokaal land management (PNGT) in Burkina Faso, doordat het een kader schept voor een harmonieuze samenwerking tussen het ‘lokaal participatieve’ en het ‘regionale’ planningsniveau.

RÉSUMÉ

Les méthodes de planification de l'utilisation des terres basées sur l'approche *'hard system*' ont généralement conduit à considérer l'activité comme un processus central de prise de décision. Cette approche longtemps associée à un exercice économique statique de haut en bas, n'a pas permis de satisfaire les besoins croissants de la population dans la plus part des pays en voie de développement. Avec l'introduction des approches participatives dans les programmes de développement telles que la *gestion des terroirs* (GT), il est devenu essentiel pour les planificateurs d'élaborer et mettre en œuvre des stratégies d'utilisation des terres basées sur les objectifs, perceptions et connaissances des populations locales.

Dans le cadre l'approche *gestion des terroirs,* des informations collectées à l'aide de la MARP (Méthode Accélérée de Recherche Participative) servent de base au processus de planification participative. Malgré la richesse de ces informations, des moyens plus efficients de collecte de l'information géographique ainsi que des outils analytiques pertinents pouvant soutenir une négociation efficace entre les différents acteurs font cruellement défaut. En outre, il y a un besoin urgent de mettre au point des méthodes permettant une intégration harmonieuse entre les niveaux de planification locale et régionale, en vue d'impulser un processus cohérent d'une planification ascendante.

Cette étude a avait pour but de développer une méthode rationnelle utilisant des outils de Géo information, permettant l'intégration de la planification participative locale et régionale pour une gestion durable des ressources naturelles. Elle est basée sur une étude de cas relative à la planification participative de l'utilisation des terres dans la province du Houet, dans le sud ouest du Burkina Faso.

Le Chapitre 1 donne une introduction générale à la thèse. Il analyse les fondements théoriques et le contexte de la planification participative de l'utilisation des terres au Burkina Faso et définit les motivations, objectifs ainsi que le cadre de l'étude.

Le chapitre 2 étudie une méthode contribuant à lier la MARP au système d'information géographique (SIG). Dans le cadre de la planification de l'utilisation des terres dans le village de Kadomba, des informations collectées à l'aide de la MARP ont été utilisées comme *inputs* dans un SIG, permettant d'effectuer une analyse spatiale. Pour cela, les principaux facteurs déterminant la définition des unités de gestion des terres telles que perçues par les différents acteurs ont été identifiés et discutés. L'exploitation des données de la MARP a permis d'identifier les différents acteurs ainsi que les facteurs qui contribuent à la création de sous unités de gestion. Cela a permis de mieux comprendre les stratégies locales de l'utilisation des terres en vue de leur utilisation ultérieure pour une analyse spatiale à l'aide du SIG. La définition des unités de gestion a consisté à: (1) l'identification à l'aide de données MARP et des données d'enquêtes, des facteurs tant internes (socioculturels, économiques et biophysiques) qu'externes au terroir qui contribuent à la création d'entités géographiques spécifiques de gestion de ressources naturelles. (2) la description et la cartographie des zones d'utilisation des terres à l'aide

de ces différents facteurs; (3) la cartographie des entités géographiques oú doivent être menées des activités spécifiques de gestion des terroirs permettant la réalisation des objectifs définis dans le cadre de la planification participative locale.

Dans le chapitre 3, il est proposé une approche spatiale pour l'intégration de la planification participative locale dans une planification régionale, contribuant à développer une méthode ascendante de planification de l'utilisation des terres. Dans les méthodes traditionnelles de planification régionale, des problèmes d'intégration entre les deux niveaux subsistent malgré les efforts remarquables de recherche. Ceux ci sont inhérents à l'approche *'hard system'* consistant à étudier séparément les composantes biophysiques et socio-économiques d'un système d'utilisation des terres, pour ensuite tenter de les lier à l'aide de modèles. Dans la planification participative, l'intégration entre les deux niveaux doit contribuer à faciliter la communication et la coopération entre les différentes parties prenantes, en vue d'une utilisation plus efficiente et durable des ressources naturelles. Pour lier de façon cohérente ces deux niveaux, il est proposé une approche bi-directionnelle capable d'opérer une transformation spatiale de l'information issue d'un niveau pour servir *d'input* à l'autre niveau. Cette méthode est basée sur les principes et procédures d'abstraction des données géographiques, développés dans la théorie de traitement des données spatiales. Elle considère le terroir villageois comme l'entité géographique de base à la quelle sont rattachés des attributs spatiaux (par exemple les unités spécifiques de gestion des ressources naturelles) et non spatiaux (facteurs socioculturels et économiques). Dans une base de données spatiales contenant l'ensemble des terroirs de la province du Houet, une analyse spatiale basée sur l'utilisation de ces attributs a permis de déterminer l'impact des contraintes locales de la *GT* sur le niveau régional et *vice versa.* Ainsi, il a été possible de déterminer l'impact des contraintes socioculturelles et économiques (régimes fonciers, manque de main d'œuvre et contraintes de temps notamment) sur la généralisation des activités de GT à l'échelle de la province. En permettant ainsi de proposer des solutions alternatives aux décideurs, ces résultats peuvent être utilisés comme aide à la décision au niveau régional ou à orienter de nouvelles politiques de développement régional. De même, dans le sens descendant, il a été possible d'identifier les zones ou l'impact de certaines activités de planification régionale pourraient compromettre les plans locaux de développement et de gestion des terroirs.

Le chapitre 4 propose un système expert comme moyen d'intégration des perceptions et connaissances locales dans des méthodes utilisant des techniques avancées telle que le SIG. Cela, permet de proposer des solutions régionales durables pour des questions cruciales relatives à la gestion des ressources naturelles, telle que la dégradation des terres. En se basant sur ce cas spécifique, cette méthode intègre les connaissances locales (utilisées comme connaissances d'experts) avec des données biophysiques, socio-économiques et socio-culturelles organisées sous formes de couches SIG. Elle permet de classifier les différentes zones de dégradation vue du niveau régional, en utilisant des règles de probabilité de Bayes. Les informations contenues dans les couches SIG ont été introduites dans le système expert et ajustées avec les informations contenues dans '*la base de connaissance'*, construite à partir de connaissances locales.

Les sources d'évidence sont constituées de paramètres biophysiques et socio-économiques tirés des perceptions locales. Les informations ont été collectées auprès des producteurs à l'aide des outils MARP au cours des diagnostiques participatifs menés dans la zone d'étude. En vue de valider le système expert, les probabilités *a priori* (utilisées comme règles dans *la base de connaissance*) ont été déterminées de façon participative avec les membres comités villageois de gestions des terroirs des villages échantillons. Un test de justesse du système expert effectué à partir de données collectées dans un échantillon indépendant de 50 villages a donné un résultat de 82%. En superposant la carte créée par le système expert avec les couches SIG représentant les différentes variables de dégradation des terres (les sources d'évidence) il a été possible d'analyser l'impact des facteurs biophysiques et socio-économiques. L'étude a montré par exemple que le zones de faible dégradation correspondent en majeure partie aux terroirs villageois ou s'exécutent des activités des gestion des terroirs.

Le chapitre 6 explore la possibilité d'utiliser le système expert comme outil servant à évaluer la l'état de la durabilité (risque de dégradation) des différents terroirs à partir du niveau régional. Dans un premier temps une comparaison a été faite entre d'une part la carte produite par le système expert et d'autre part, une carte produite par un modèle d'équilibre des éléments nutritifs ainsi qu'une carte de la dynamique de la végétation basée sur des données sur l'indice de la végétation (NDVI) du système NOAA. En utilisant les résultats de la cartographie participative de la dégradation des terres dans les villages échantillons comme références, l'étude a montré que le système expert a obtenu les meilleurs résultats avec une concordance de plus de 80% alors le modèle de l'équilibre des éléments nutritifs a obtenu environ 70% et la carte de la dynamique de la végétation seulement 42%. Dans un deuxième temps, le système expert a été utilisé pour développer différents scénaris correspondant aux objectifs définis par les producteurs dans le cadre de la GT. La procédure a consisté à pondérer les paramètres qui dans chaque cas, favorisent la dégradation, contribuant à changer les règles de probabilité dans la *base de connaissance* du système expert. Selon les résultats obtenus, le scénario de conservation de l'environnement reflète au mieux l'état de la dégradation telle que perçue par les populations locales. Le scénario d'accroissement de la production agricole et celui de d'accroissement des revenus des ménages prédisent tous deux une dégradation plus accrue, indiquant une faible proportion de zones faiblement dégradées et une très forte proportion de zones fortement dégradées (plus du tiers de la province). Le scénario de lutte anti érosive (prenant uniquement en compte les paramètre biophysiques) prédit la meilleure situation (seulement 8% de la superficie totale de la province comme fortement dégradée alors que les zones faiblement dégradées couvriraient jusqu'à 25% du territoire). La pire situation est prédite par le scénario pour l'amélioration des conditions sociales, indiquant que les zones fortement dégradées couvriraient presque la moitié de la province.

Dans le Chapitre 6, une méthode liant la MARP et le SIG a été proposée, permettant de cartographier les zones à risque de conflit dans un processus ascendant de planification de l'utilisation des terres. Dans la gestion des terroirs, des mécanismes permettant de prédire l'impact spatial des facteurs de risques de conflits locaux doivent accompagner le

processus de planification dans le but d'améliorer la négociation entre les parties prenantes. Dans ce chapitre, il a été proposé une approche prédisant les zones à risque de conflits de gestion des ressources naturelles. Elle est basée sur des méthodes d'analyse *interprétative et prescriptive*. Une analyse des parties prenantes a permis d'identifier les principaux acteurs ainsi que leurs intérêts. Cette analyse a permis de proposer une typologie des principaux conflits, basée sur des clés multiples. Les conflits tels que perçus par les populations locales ont été analysés à l'aide des outils de la MARP et des questionnaires d'enquêtes en vue d'identifier les principales causes. Les données de la MARP ont également servi à cartographier les zones à risque de conflit à l'échelon de la zone du projet pilote du PNGT dans le Houet. L'étude a ensuite montré que les populations locales perçoivent le problème de la pression démographique comme étant le principal facteur de risque des conflits. Ce facteur a servi de base pour créer un indice de *'pression sur les zones cultivables'* et *un indice de 'pression sur les pâturages'*, en utilisant des données biophysiques et socio-économiques. Ces indices ont été utilisés pour cartographier à l'aide du SIG les zones à risque à l'échelle de la province. En utilisant un modèle de régression, l'hypothèse selon laquelle les conflits sont fonction de: la compétition pour les ressources naturelles, l'insécurité et la précarité des droits d'accès, l'insuffisance ou l'absence d'autorité a été prouvée.

REFERENCES

Abbot, J., Chambers, R., Dunn, C., Harris, T., Porter, G., Townsend, J., Weiner, D. and de Merode, E. (1998). Participatory GIS: opportunity or oxymoron. *PLA Notes. International Institute for Environment and Development*, **33**(7), 27 - 34.

Adriance, D. (1995). PRA in a health education, water and sanitation project in Kenya. *PLA Notes. International Institute for Environment and Development IIED London, UK*, **22**, 41 - 44.

Al Kodmany, K. (2001). Bridging the gap between technical and local knowledge: Tools for promoting community-based planning and design. *Journal of Architectural and Planning Research.* **18**(2), 110 - 130.

Albaladejo, J., and Stocking, M. (1989). Comparative evaluation of two models in predicting storm soil loss from erosion plots in semi-arid Spain. *Catena*, **16**(3), 227-236.

Aronoff, S. (1989). *Geographic information systems: a management perspective*. WDL Publications, Ottawa.

Bajtes, N. H. (1996). Global assessment of land vulnerability to water erosion on a ½ ^{o} by ½ ^{o} grid. *Land degradation and development*, **Vol 7**, 353-365.

Balachandran, C. S., and Fisher, P.F. (1990). DESERT: a prototype expert system to advise on land degradation control. *Land Degradation and Rehabilitation*, **2**(1), 27-41.

Balachandran, C. S. (1995). LACONEX: a rule-based implementation to advise on plot-level land conservation in Vilathikulam southeastern India. *Land Degradation and Rehabilitation*, **6**(4), 265-283.

Batterbury, S. (1998). Local environmental management, land degradation and the 'gestion des terroirs' approach in West Africa: policies and pitfalls. *Journal of International Development*, **10**(7), 871-898.

Beek, K. J., de Bie, C. A., and Driessen, P. M. (1996). Land Evaluation (FAO Method) for Sustainable Land Use Planning and Management: Status and Perspectives. *Latin American Soil Science Congress, Aguas de Lindoia-SP 4-8 August 1996*, Aguas de Lindoia-SP Brazil.

Bell, D., Raiffa, H. and Versky, A. (1989). Decision-making: Descriptive, Normative and Prescriptive Interaction. Cambridge University Press. Cambridge.

Berry, J. K. (1993). GIS resolves land use conflicts: A case study. *Intenational GIS source book*.

Biot, Y., Blaikie, P.M, Jackson, C., and Palmer-Jones, R. (1995). *Rethinking research on land degradation in developing countries*. World Bank, Washington, D.C. USA.

BIT-ACOPAM. (1996). *Module introduction a la gestion des terroirs: manuel de formateurs*, Dakar.

Blaikie, P., and Brookfield, H. (1987). *Land degradation and society*. Methuen, London etc.

Blench, R. M. (1997). Aspects of Resources Conflict in Semi-Arid Africa. *Natural Resource Perspectives*, **Vol.16**, Overseas Development Institute (ODI). London, 16 p.

Blench, R. M., Driver, T., Haour, A., and Hendrie, B. (1998). *Resource conflict in semi-arid Africa: an essay with an annotated bibliography*. Overseas Development Institute (ODI). London.

Boardman, J., Evans, R., Favis-Mortlock, D.T., and Harris, T.M. (1990). Climate change and soil erosion on agricultural land in England and Wales. *Land-Degradation and Rehabilitation*, **2**(2), 95-106.

Boerboom, L. G. J. (1999). A soft system approach to implicit water resources conflicts in a Philippine watershed: stakeholder analysis and development of a group decision support system for land use optimization. PhD Thesis University of Georgia. Athens, 192 p.

Bojorquez, T. L. A., Dias, M.S., and Ezcurra, E.S.O. (2001). GIS-based approach for participatory decision-making and land suitability assessment. *International Journal of Geographical Information Science*, **15**(2), 129-151.

Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure.* Allen & Unwin, London.

Boudet, G. (1978). Manuels et précis d'élevage: manuel sur les pâturages tropicaux et les cultures fourragères. *La Documentation Française* Vol. 4. IEMVT, Maison Alfort, 258 p..

Boulet, R., and Leprun, J. (1969). Etudes pédologiques de la Haute Volta: Région sud-ouest. ORSTOM. Dakar.

Bridges, E. M., and Oldeman, L.R. (1999). Global assessment of human-induced soil degradation. *Arid Soil Research and Rehabilitation*, **13**(4), 319-325.

Briggs, D. J., Brignall, P., and Wilkes, A. (1989). Assessing soil erosion risk in the Mediterranean region: the CORINE program of the European community, EU. Wageningen, pp. 195 - 210.

Brinkman, R. (1994). Recent Development in Land Use Planning with Special reference to FAO. In L. O. Fresco et al. *(E*ds) *The future of the land: mobilising and integrating knowledge for land use options.* John Wiley & Sons Ltd. Chichester.

Buckles, D. (1999). Cultivating peace. Conflict and collaboration in Natural Resource Management, International Research Development Centre (IRDC); The World Bank. Ottawa: Washington etc., 285 p.

Budelman, A., Mizambwa, F., Stroud, A., and Kileo, R. (1995). The application of nutrient flow analysis in land use dynamics: The case of north Sukumaland land zone, Tanzania. *Workshop on Nutrient Cycling and Soil Fertility Management in Africa*, 26 November, 2 December 1995. Soddo, Ethiopia. IIED London.

Burrough, P. A. (1986). *Principles of geographical information systems for land resources assessment*. Clarendon Press, Oxford.

Camara, O. S. (1996). Utilisation des résidus de récolte et du fumier dans le Cercle de Koutiala: Bilan des éléments nutritifs et analyse économique. Rapport PPS No 18. Wageningen, 120 p.

Campbell, A. (1992). Community first: Landcare in Australia. Paper presented to the Workshop `Beyond Farmer First: Rural people's knowledge, agricultural research and extension practice'. Brighton, October 27-29, 1992, (Ed)Brighton/IIED, IDS. London.

Capo-Chichi, Y. J., Toe, E., Coulibaly, M., Lompo, A. (1995). Bilan des acquis des expériences gestion des terroirs. PNUD/FAO. Volume 1.

Carranza, E. J. M. (2002). Geologically constrained mineral potential mapping: examples from the Philippines, PhD Thesis ITC Dissertation No. 86. ITC: Technical University of delft. Enschede, Delft 480 p.

Carver, S. (2001). Participation and Geographical Information: a Position Paper. *Paper presented at the "ESF-NSF Workshop on Access to Geographic Information and Participatory Approaches Using Geographic Information", Spoleto, 6-8 December 2001. http://www.iapad.org/bibliography.htm*.

CEC. (1992). CORINE soil erosion risk and important land resources in the southern regions of European Communities: An assessment and evaluation to evaluate and map the distribution of land quality and soil erosion risk. In *Official Publication of the European Union*. Brussels, etc, 97 p.

Ceccarelli, T. (1996). Multicriteria and GIS analysis in support of land use planning: an example from the Zambezi valley. *Conf. on the application of remotely sensed data and GIS in environmental and natural resources assessment in Africa*, March 15 - 22 1996, Harare.

Cernea, M. M. (1991). Putting people first: sociological variables in rural development. (Ed) M. M. Cernea, Oxford University Press. New York etc., 575 p.

Chambers, R. (1980). *Rural Rapid Appraisal: Rational and repertoire.* Institute of Development Studies, Sussex University, Sussex.

Chambers, R. (1983). *Rural development: Putting the last first*. Longman Scientific & Technical, Harlow.

Chambers, R., Pacey, A., and Thrupp, L.A. (1989). Farmer innovations and agricultural research. *Intermediate Technology*. London, 219 p.

Chambers, R. (1992). *Rural Rapid appraisal: rapid, relaxed and participatory discussion*. *Paper*

331. Ed. IDS, Brighton.

Chambers, R. (1994a). Participatory rural appraisal (PRA): challenges, potentials and paradigm. *World-Development.* **22**(10), 1437-1454.

Chambers, R. (1994b). The origins and practice of participatory rural appraisal. *World Development.* **22**(7), 953 - 969.

Chambers, R. (1994c). Participatory rural appraisal (PRA): analysis of experience. *World-Development.* **22**(9), 1253 - 1268.

Check land, P., and Scholes, J. (1990). *Soft Systems Methodology in Action.* John Wiley & Sons, Chichester.

Chokor, B. A., and Odermo, F. O. (1994). Land degradation assessment by small-scale traditional African farmers and implications for sustainable conservation management. *Geoforum*, **25**(2), 145-154.

Conway, G. R. (1985). Agricultural ecology and farming systems research. *Agricultural Systems Research for Developing Countries.* Australian Centre for International Agricultural research (ACIAR)

Conway, G. R. (1987). The properties of agroecosystems. *Agricultural Systems*, **24**(2), 95-117.

Cornwall, A., Guijt, I. and Welbourn, A. (1993). *Acknowledging process: Challenges for Agricultural Research and Extension Methodology*. University of Sussex, Brighton.

Cousins, B. (1995). A role for common property institutions in land redistribution programmes in South Africa. In *Gatekeeper Series: Sustainable agriculture and rural livelihoods*, No. 53, International Institute for Environment and Development (IIED). London, pp. 20.

Cowen, M. P., and Shenton, R.W. (1996). *Doctrines of Development*. Routledge, London, New York.

Cowie, W. (2000). Introduction. *Canadian Journal of Development Studies*, **XXI** (Special Issues: Participatory Development), 401 - 413.

CPCS. (1967). Classification des Sols. Commission de Pédologie et de Cartographie des Sols, E.N.S.A.

Curie, D. J. (1991). Energy and large-scale patterns of animal and plant species richness. *American Naturalist*, **137**, 27 - 49.

Davis, G. B., and Olson, M.H. (1985). *Management information systems: conceptual foundations, structure, and development*. McGraw-Hill, New York.

Davis-Case, D. A. (1990). *The community's toolbox: the idea, methods and tools for participatory assessment, monitoring and evaluation in community forestry*. FAO, Rome.

De Bie, C. A., Beek, K. J., Driessen, P. M., and Zinc, J.A. (1995). Towards Operationalisation of Soil Information for Sustainable Land Management. Position Paper. *Brazil Soil Conference, July 1995*, Brazil. 20 p.

De Jager, A., Kariuke, I., Matiri, F.M., Odenko, M. and Wanojama, J.M. (1998). Monitoring nutrient budget flows and economic performance in African farming systems (NUTMON): Linking nutrient balance and economic performances in three districts in Kenya. *Agriculture, Ecosystems and Environment*, **71**(1-3), 215 -228.

De la Rosa, D., Moreno, J.A., and Garcia, L.V. (1993). Expert evaluation system for assessing field vulnerability to agrochemical compounds in Mediterranean regions. *Journal of Agricultural Engineering Research*, **56**(2), 153-164.

De Lopez, A. M., de Meijere, J., and Paresi, C. M. J. (1996). Structured development of a territorial information system in the province of Chubut. *63rd FIG permanent committee meeting and international symposium*, Buenos Aires. 278 - 287.

Defoer, T., H. de Goorte, T. Hilhorst, Kante, S. and Budelman, A. (1998). Participatory action research and quantitative analysis for nutrient management in southern Mali: A fruitful marriage? *Agriculture, Ecosystems and Environment*, **71**(1-3), 215 - 228.

Dejene, A., Shishira, E. K., Yanda, Z. P., and Johnsen, H. F. (1997). Land degradation in Tanzania.

Perception from the village. *World Bank technical paper*, No. 370, Washington D.C. 79 p.
Dent, D. (1988). Guidelines for land use planning in developing countries. *Soil Survey and Land Evaluation*, **8**(2), 67-76.
Dent, D. (1997). Policy for the management of natural resources. *Land Chatham*, **1**(1), 3-27.
Dent, D. L. (1993). What do we mean by land use planning? In *Land Evaluation for land use planning*, (Eds). D. L. Dent, and Desphande, S.B., National Bureau of Soil Survey and Land Use Planning. Nagpur, pp. 21-27.
Desmet, P. J. J., and Govers, G. (1996). A Gis procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *J. Soil and Water Conservation*, **51**(5), 427- 433.
Dirorimwe, C. (1998). Participatory development of household food security and nutrition improvement programme in Kano State, Nigeria. *Food, Nutrition and Agriculture*, **No 22**, 36 - 46.
Driessen, P. M., and Konijn, N.T. (1992). *Land Use System Analysis*. Wageningen Agricultural University, Dept of Soil and Geology. INRES, Malang.
Dugué, P. (1989). *Possibilités et limites de l'intensification des systèmes de cultures vivriers en zone Soudano-Sahelienne: Le cas du yatenga (Burkina Faso).* Montpellier.
Dumanski, J. (1997). Criteria and indicators for land quality and sustainable land management. *ITC Journal*, **1997(3-4)**, 216-222.
Dumanski, J., and Pieri, C. (2000). Land quality indicators: research plan. *Agriculture, Ecosystems and Environment*, **81**, 93 - 102.
Eger, H., Von Lossau, A., Muller, U., and Scwedersky, T. (1997). Stratégies, méthodes et instruments de la gestion des terroirs: l'approche de la GTZ. *Agriculture et développement rural*, **1/97**, 20 - 21.
Elwell, H. A., and Stocking, M.A. (1982). Developing a simple yet practical method of soil-loss estimation. *Tropical-Agriculture*, **59**(1), 43-48.
Engberg, P. L., Brimer, L., Krogh, L. and Meyer, M. (1993). Local natural resources management in Burkina Faso: constraints and opportunities. *Proceedings of the 5th Sahel Workshop,4-6 January 1993*, Niamey. 63-67.
Engberg, P. L. (1995). Creating local democratic politics from above: the 'Gestion des Terroirs' approach in Burkina. In *Dryland Programme. IIED Issue Paper* No. 54. London. UK. 33 p.
Engel, B. A., Jones, D.D., and Thompson, T.L. (1992). Integrating expert systems with traditional computer-based problem solving techniques. *AI Applications in Natural Resource Management*, **6**(2), 5-12.
Eweg, H. P. A., van Lammeren, R., Deurloo, H., and Woldu, Z. (1998). Analysing degradation and rehabilitation for sustainable land management in the highlands of Ethiopia. *Land Degradation and Development*, **9**(6), 529-542.
Faeth, P. (1993). An economic framework for evaluating agricultural policy and the sustainability of production systems. *Agriculture, Ecosystems and Environment*, **46**(1-4)), 161-173.
FAO. (1976). *A framework for land evaluation.* FAO, Rome, Italy.
FAO. (1983). *The training of group promoters in field projects of the Peoples' Participation Programme.* FAO, Rome.
FAO. (1985). *Guidelines. Land evaluation for irrigated agriculture*, Rome, Italy.
FAO. (1993). *Guidelines for land use planning. FAO Development series1*. FAO, Rome.
FAO. (1995). *Planning for sustainable use of land resources. Towards a new approach*. Food and Agriculture Organization, Rome, Italy.
FAO-UNEP. (1995). *Negotiating a sustainable future for the land. An integrated approach to the planning and management of land resources.* FAO Rome.
Farshad, A., and Zinck, J.A. (1993). Seeking agricultural sustainability. *Agriculture Ecosystems and Environment*, **47**(1), 1-12.

Fischer, M. M. (1994). Expert systems and artificial neural network for spatial analysis and modelling: Essential components for knowledge-based geographical information systems. *Geographical Systems*, **vol. 1**, 221-235.

Freda, k. (1995). Decision support for natural resources management: models, GIS, and expert systems. *AI Applications*, **9**(3), 3 - 19.

Freire, P. (1972). *Pedagogy of the oppressed*. Penguin. Harmondsworth, U.K.

Fresco, L., Huizing H. G. J., Van Keulen, H., and Luning, H.A. (1990). *Land evaluation and farming systems analysis for land use planning: FAO guidelines*. FAO: ITC: Wageningen Agricultural University, Rome: Enschede: Wageningen.

Fresco, L., Huizing H. G. J., Van Keulen, H., and Luning, H.A. (1992). *Land evaluation and farming systems analysis for land use planning: FAO guidelines*. FAO: ITC: Wageningen Agricultural University, Rome: Enschede: Wageningen.

Gasteyer, S., and Flora, C. B. (2000). Measuring ppm with tennis shoes: Science and locally meaningful indicators of environmental quality. *Society Natural Resources*, **13**(6), 589 - 597.

Genovese, G., Vignolles, C., Negre, T., and Passera, G. (2001). A methodology for a combined use of normalised difference vegetation index and CORINE land cover data for crop yield monitoring and forecasting. A case study on Spain. *Agronomie*, **21**(1), 91-111.

Giarratano, J., and Riley, G. (1994). *Expert systems: principles and programming*. PWS, Boston.

Gilbert, E. H., Norman, D.W, and Winch, F.E. (1980). Farming System Research: A Critical Appraisal. In *MSU Rural Development Paper*, Vol. 6. (East Lansing, Michigan State University).

Gitelson, A. A., Kogan, F., Zakarin, E., Spivak, L., and Lebed, L. (1998). Using AVHRR data for quantitative estimation of vegetation conditions: calibration and validation. *Advances in Space Research*, **22**(5), 673-676.

Gonzalez, A. J., and Dankel, D.D. (1993). *The engineering of knowledge based systems: theory and practice*. Prentice-Hall, Englewood Cliffs.

Gonzalez, R. M. (2000). Platforms and terraces: bridging participation and GIS in joint-learning for watershed management with the Ifugaos of the Philippines. PhD Thesis ITC, Wageningen Agricultural University. Enschede: Wageningen. 186 pp.

Goodchild, M. F. (1990). Applications issues in GIS: NCGIA core curriculum. (Eds). M. F. Goodchild, and Kemp, K.K., NCGIA, University of Californa. Santa Barbara. 250 p.

Gottlieb, P., and Reilly, J.A. (1994). Simulation model for state growth management planning and evaluation: the New Jersey case. *Computers, Environment-and Urban-Systems.* **18**(1), 43-53.

Gray, L. C. (1999). Is land being degraded? A multi-scale investigation of landscape changes in Southwestern Burkina Faso. *Land Degradation and Development*, **10**, 329 - 343.

Gray, L. C., and Kevane, M. (2001). Evolving tenure rights and agricultural intensification in Southwestern Burkina Faso. *World Development*, **Vol 29**(No 4), pp 573 - 587.

Grenier, L. (1998). *Working with indigenous knowledge: a guide for researchers.* International Development Research Centre (IDRC), Ottawa.

Grimble, R., and Wellard, K. (1997). Stakeholder methodologies in natural resource management: a review of principles, contexts, experience and opportunities. *Agricultural Systems*, **55**(2), 173-193.

Groten, S. M. E. (1990). Regression and correlation in monitoring applications: FAO - ITC ARTEMIS and GIS training course for food security early warning. 12 Nov. -7 Dec 1990. RCSSMRS. Nairoby. 22p.

Groten, S. M. E. (1992). *Monitoring Sahelian agroecosystems using NOAA vegetation index data: compilation of articles from monitoring research at or related to ITC*. ITC, Enschede.

Groten, S. M. E. (1993). NDVI - crop monitoring and early yield assessment of Burkina Faso.

International Journal of Remote Sensing, **14**(8), 1495-1515.
Groten, S. M. E. (1997). Air Photos as means of communication in land Management. *Agriculture and Rural Development*, **4**(1), 11-14.
Groten, S. M. E. (1998). GIS in a participatory land use planning process. *European PostGraduate Course in Environmental Management (EPCEM)*, November 18, 1998, Amsterdam. 11 p.
Groten, S. M. E., Immerzel, W., and van Leeuwen, L. (1999). *Monitoring of crops, rangelands and food security at national level*. ITC: FAO, Enschede, Rome.
Groten, S. M. E., and Bogere, R. (2001). Modeling of sustainability of agropastoral land use systems with GIS: model development and case study of semi - arid communal land areas in Zimbabwe. In *Landscape ecology applied in land evaluation*, (Eds). v. d. D. Zee, and I. S. Zonneveld. ITC Publication No. 81: IALE Publication MM-1: Enschede
Grunblatt, J., Ottichilo, W. K., and Sinange, R. K. (1992). A GIS approach to desertification assessment and mapping. *Journal of Arid Environments*, **23**(1), 81-102.
Gueye, M. B., and Freudenberger, K.S. (1991). *Introduction a la Methode Acceleree de Recherche Particicpative. Quelques Notes pour Appuyer une Formation Pratique*. IIED, Londres.
Gueye, M. B. (1992). *Conflits et alliances entre agriculteurs et eleveurs: Le cas du Goll de Fandene. Programme " Reseau des Zones Arides "*. IIED., London.
Hadi, A. (2000). A participatory approach to sanitation: experience of Bangladeshi NGOs. *Health, Policy and-Planning.* **15**(3), 332-337.
Haeringen, R. V. (1988). Approach to local-level land-use planning for basic needs fulfilment and sustainability. *Local level planning for sustainable land use*, Wageningen Agricultural University. Wageningen
Harris, F. (1998). Farm level assessment of the nutrient balance in northern Nigeria. *Agriculture, Ecosystems and Environment*, **71**(1-3), 215 228.
Harry, E., and Pople, J.R. (1982). Heuristic methods for imposing structure on ill-structured problems: The structuring of medical diagnostics. *Artificial Intelligence in Medicine*, In Peter Szolovits (Ed) Westview Press, Boulder CO, 119-190.
Henneman, R., Groten, S.M.E., and Williams, J. (1998). Geographical Information Systems (GIS) for rural development in sub-Saharan Africa. Summary Report of a CTA/ITC workshop, Enschede, The Netherlands, 23-26 09 1997.
Hoek, A. v. d. (1992). *Planning as a Learning process: A strategy for planning land use programmes at local level with special reference to the uplands of Java*. Wageningen
Howorth, C., and O'Keefe, P. (1999). Farmers do it better: Local management of change in southern Burkina Faso. *Land Degradation and Development*, **10**(2), 93-109.
Huang, X., and Jensen, J.R. (1997). A machine-learning approach to automated knowledge-base building for remote sensing image analysis with GIS data. *Photogrammetric Engineering and Remote Sensing*, **63**(10), 1185-1194.
Hueting, R., and Reijnders, L. (1998). Sustainability is an objective concept. *Ecological Economics.* **27**(2), 139-147.
Hurni, H. (1997). Concepts of sustainable land management. *ITC Journal.* **1997(3-4)**, 210-215.
Hurni, H. (2000). Assessing sustainable land management (SLM). *Agriculture, Ecosystems and Environment*, **81**, 83 - 92.
IFAD. (1992). Soil and water conservation in sub-Saharan Africa. Towards sustainable production by the rural poor. Free University of Amsterdam. Centre for Development Cooperation Services.
IIED. (1998). *Land Tenure and Resource Access in West Africa: Issues and Opportunities for the Next Twenty-Five Years.* International Institute for Environment and Development (IIED), London. UK.
Ikerd, J. E. (1993). The need for a system approach to sustainable agriculture. *Agriculture, Ecosystems and Environment*, **6**, 147-160.

INERA. (1998). "Historique de la dynamique du Terroir de Kadomba, Province du Houet". PNGT.

INSD. (1998). *Recensement général de la population et de l'habitation du Burkina Faso (10 au 20 Décembre 1996): Population résidente des départements, communes, arrondissements et provinces.* Institut National de la Statistique et de la Démographie, Ouagadougou.

IOV. (1994). Environment and development cooperation: evaluation of Netherlands aid policy with regards to the environment, with special reference to Burkina Faso, Indonesia and Kenya. Ministry of Foreign Affairs, Operations Review Unit (IOV).

Janssen, R. (2001). On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. *Journal of Multi - Criteria Decision Analysis*, **10(2001)**, 101-109.

Kessler, J. J., and Geerling, C. (1994). *Profil Environnemental du Burkina Faso*. Université Agronomique de Wageningen, Département de l'Aménagement de la Nature, Wageningen.

Kote, G., Ouedraogo, B., Ouedraogo, H. M. G., Tallet, B. (1998). La sécurisation foncière en milieu rural, PNGT. Ouagadougou. 68 p.

Kremenyuk, V. (1991). International negotiation: Analysis, approaches, issues. Jossey-Bass Publisher. Oxford.

Krogh, L. (1997). Field and village nutrient balances in millet cultivation in northern Burkina Faso: A village case study. *Journal of Arid Environments*, **35**(1), 147-159.

Kuperus, S. (1987). Participation in Forestry. *People's Participation in Social forestry Projects*, Wageningen.

Lambin, E. (1993). Spatial scale and desertification. *Desertification control Bulletin*, **23**, 20- 23.

Leach, M., and Mearns, R. (1996). The lie of the land: challenging received wisdom on the African environment. International African Institute (in associating with J. Currey and Heinemann). London.

Lein, J. K. (1992). On the application of expert systems in environmental performance assessment. *Journal of Environmental systems*, **21**(2), 167 - 183.

Leung, Y. (1992). Towards the development of an intelligent decision support system. In *Geographical information systems, spatial modelling and policy evaluation*, (Ed) Y. Leung, Springer. Berlin etc: pp. 131-145.

Lewis, J. (1996). Community-based management: the 'Gestion des Terroirs' approach. In *Desertification Control Bulletin. United Nations Environment Programme (UNEP)*, Vol. 28. Nairobi, Kenya, pp. 42-43.

Lindskog, P., and Tengberg, A. (1994). Land degradation, natural resources and local kowledege in the Sahel zone of Burkina Faso. *GeoJournal*, **33**(4), 365-375.

Loader, R., and Amartya, L. (1999). Participatory Rural Appraisal: extending the research method base. *Agricultural systems*, **62**, 73 - 85.

Lobo, A. (1995). Temporal signatures of NDVI: vegetation types and primary production. *Photosynthesis and remote sensing*, Montpellier. (EARSeL). 465-468.

Lompo, F., Bonzi, M., Zougmore, R., Youl, S. (2000). Rehabilitating soil fertility in Burkina Faso. In *Nutrients on the move. Soil fertility dynamics in African farming systems*, (Eds). T. Hilhorst, and Muchema, F., IIED. London, pp. 103-118.

Luning, H. A. (1986). Survey comes of age? Inaugural address upon his official acceptance of the office op professor of survey integration for development at the International Institute for Aerospace Survey and earth Sciences (ITC). Enschede.

Luning, H. A. (1994). Planning and management of land resources at the local level: some experiences from eastern and southern Africa. In *No easy way out: essays on 3rd world development in honour of Hinderink*, (Eds) H. A. Broekhuis, and Verkoren, O. Nederlandse Geografische Studies Vol. 186, pp. 250 - 259.

Maatman, A. (2000). Si le fleuve se tord, que le crocodile se torde: Une analyse des systèmes agraires de la région Nord-Ouest du Burkina Faso a l'aide des modèles de programmation

mathématiques. *Centre for Development Studies*, University of Groningen. Groningen.
Malczewski, J. (1997). Multicriteria group decision-making model for environmental conflict analysis in the Cape Region, Mexico. *J. of Environmental Planning & Management*, **40**(3), 349 - 374.
Mallawaarachchi, T., Walker, P.A, Young, M.D, Smyth, R.E., Lynch, H.S., and Dudgeon, G. (1996). GIS-based integrated modelling systems for natural resource management. *Agricultural Systems*, **50**(2), 169-189.
Malton, P. (1994). Indigenous land use systems and investments in soil fertility in Burkina Faso. In *Searching for land tenure security in Africa*, (Eds). J. Bruce, and Migot-Adholla, S. Dubeque, IA: Kendall Hunt, pp. 41 - 69.
Mascarenheras, J., Shah, P., Joseph, S., Jayakaran, R., Devavaram, J., Ramachandran, V., Fernandez, A., Chambers, R., and Pretti, J. (Eds). (1991). Participatory Rural Appraisal: Proceedings of the February 1991 Bangalore PRA Trainers Workshop. In *RRA Notes*, Vol. 13, Sustainable Agriculture Programme. IIED, London. UK, Bangalore India, pp. 143.
Maxwell, S., and Bart, C. (1995). *Beyond ranking: exploring relative preferences in P/RRA*. International Institute for Environment and Development (IIED), London; UK.
Mazzucato, V., and Niemeijer, D . (2000). Rethinking soil and water conservation in changing society. A case study in eastern Burkina Faso. Wageningen University Tropical Resource management Papers, 32 Wageningen 380 p
Mazzucato, V., and Niemeijer, D. (2001). Overestimating land degradation, underestimating farmers in the Sahel. Wageningen.
Mellerowicz, K. T., Rees, H.W., Chow, T.L., and Ghanem, I. (1994). Soil conservation planning at the watershed level using the Universal Soil Loss Equation with GIS and microcomputer technologies: a case study. *Journal of Soil and Water Conservation*, **49**(2), 194-200.
Merchant, J. W. (1994). GIS-based groundwater pollution hazard assessment: a critical review of the DRASTIC model. *Photogrammetric Engineering and Remote Sensing*, **60**(9), 1117-1127.
Millward, A. A., and Mersey, J. E. (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *Catena*, **38**(1999), 109-129.
Mohamed, A. A. (1999). An integrated agro-economic and agro-ecological framework for land use planning and policy analysis PhD Thesis Wageningen Agricultural University. Wageningen, pp. 188.
Molenaar, M. (1991). Terrain objects, data structures and query spaces. *Geo-informatik: Anwendungen, Erfahrungen, Tendenzen: Beitrege zum internationalen Anwenderforum 1991 Geo-Informationssysteme und Umweltinformatik.* 20 21 Februar 1991, Duisburg. 53 - 70.
Molenaar, M. (1993). Objects hierarchies and uncertainty in GIS or why the standardisation is so difficult. *Geo-Information Systems*, **Vol 6**(No 3).
Molenaar, M. (1998). *An introduction to the theory of spatial object modelling for GIS*. Taylor & Francis, London.
Moller-Jensen, L. (1990). Knowledge-based classification of an urban area using texture and context information in Landsat-TM imagery. *Photogrammetric Engineering and Remote Sensing.*, **56**(6), 899-904.
Moore, I. D., Wilson, J.P. (1992). Slope-length factors for the Revised Universal Soil Loss Equation: simplified method of estimation. *Journal of Soil and Water Conservation*, **47**(5), 423-428.
Morgan, R. P. C., Quinton, J.N., and Rickson, R.J. (1994). Modelling methodology for soil erosion assessment and soil conservation design: the EROSEM approach. *Outlook on Agriculture*, **23**(1), 5-9.
Mouat, D., Lancaster J., Wade, T., Wickham, J., Fox C., Kepner W., and Ball, T. (1997). Desertification evaluated using an integrated environmental assessment model.

Environmental Monitoring and Assessment, **48**(2), 139-156.

Mukherjee, N. (1995). *Participatory Rural Appraisal and Questionnaire survey (comparative field experience and methodological Innovations)*. Concept Publishing Company, New Delhi.

Murombedzi, J. (1991). Decentralising Common Property Resource Management: A case study of the Nyaminyami District Council of Zimbabwe's Wildlife Management Programme. In *Dryland Networks Programme, Issues Paper No.30*. IIED, London

Murphree, M. W. (1993). Communities as resource management institutions. In *Sustainable Agriculture Gatekeeper Series*, Vol. 36. IIED, London

Nair, S. V., Mohammed, D., Ganapathi, N., and Abdul-Rahman, R. (1999). Expert system for terrestrial vegetation distribution, potential impact and mitigation abatement measures. *Environmental Monitoring and Assessment*, **58**(2), 213-224.

Nancy J., O. (1999). PPGIS: The Evolution of Public Participation GIS, *http://www.iapad.org/bibliography.htm*. Indiana State University Terre Haute.

Naylor, C. (1989). How to build an unferencing engine. In *Expert Systems: Principles and Case Studies*, (Ed) R. Forssyth, Chapman & Hall. London.

Newton, S. L., Yves, L.G. and Khosrow, D. (1897). Quantitative Models for Reasoning under Uncertainty in Knowledge-Based Expert Systems. *International Journal of Intelligent Systems*, **II**, 15-38.

Niemeijer, D., and Mazzucato, V. (2001). Productivity of soil resources in Sahelian Villages. In *Agro-Sylvo-Pastoral Land Use in Sahelian Villages*, (Eds) L. Stroosjnijder, and van Rheenen, T. Advances in Geo-ecology Vol. 33, IUSS. Wageningen, pp. 145-165.

Nurse, M. C., Singh, H. B., Paudyal, B. R., Bonjan, S., and Riley, J. (1993). Beat-level planning: development of a management information system for community forestry. Second National Community Forestry Workshop. Vol. 4 (1). Nepal Banko-Janakari, pp. 91-95.

Nyerges, T., Jankowski, P. and Drew, C. (2002). Data-gathering strategies for social-behavioural research about participatory geographical information information use. *International Journal of Geographical Information Science*, **16**(1), 1-22.

Oakley, P., et al. (1991). Projects with people: the practice of participation in rural development, International Labour Office. Geneva, 284 pp.

Oldeman, L. R., Hakkeling, R.T.A., and Sombroek, W.G. (1990). World Map of the status of human-induced soil degradation (GLASOD). An Explanatory Note. ISRIC-UNEP.

O'looney, J. (2000). *Beyond maps: GIS and decision making in local government*. ESRI, Redlands.

Ouedraogo, H. (1993). Population et développement dans la province du Houet, Ministère de l'Economie te du Plan. Secrétariat Permanent du Conseil National de la Population (CONAPO. Ouagadougou, pp. 46.

PAGIFS. (1998). *Plan d'action de gestion intégrée de la fertilité des sols 2000 - 20005.* Ministère de l'Agriculture, Ouagadougou.

Paliniswamy, A., Subramanian, S. R., Pretti, J. N., and John, K. C. (1992). *Participatory Rural Appraisal for Agricultural Research at Paiyur, Tamil Nadu.* Coimbatore: Centre for Agricultural and Rural Development Studies, IIED. London.

Pare, L., and Tallet, B. (1999). D'un espace ouvert a un espace sature: Dynamique foncière et démographique dans le département de Kouka (Burkina Faso. *Espace Populations Sociétés*, **1**, 83-92.

Pare, L. (2001). *Negotiating rights: access to land in the cotton zone, Burkina Faso*. International Institute for Environment and Development (IIED), London; UK.

PNGT. (1993). Les grandes orientations en matière de gestion des terroirs au Burkina Faso. Programme National de Gestion des Terroirs. Ouagadougou

Poffenberger, M., and Mc Gean, B. (1992). From conflict to collaboration: Asian experiences with Joint Forest Management. Paper presented to the SAREC Workshop on People's participation in the Management of Natural Resources, Stockholm 5-6th 1992.

Pretty, J. N., and Guijt, I. (1992). Primary environmental care: an alternative paradigm for development assistance. *Environment and Urbanization*, **4**(1), 22-36.

Pretty, J. N. (1998). Supportive policies and practice for scaling up sustainable agriculture. In *Facilitating Sustainable Agriculture. Participator learning and adaptative management in times of environmental uncertainty*, (Ed) N. G. Röling, and M. A. E. Wagemakers, Cambridge University Press, pp. 23-45.

Prudencio, C. Y. (1993). Ring management of soils and crops in the West African semi-arid tropics: the case of the Mossi farming system in Burkina Faso. *Agriculture, Ecosystems and Environment*, **47**(3), 237-264.

Rabbinge, R., and van Ittersum, M.K. (1994). Tensions between aggregation levels. In *The future of the land: mobilising and integrating knowledge for land use options: (E*d). Fresco et al., Wiley & Sons. Chichester, pp. 409.

RAF. (1984). *Texte portant réorganisation agraire et foncière*, Ouagadougou.

RAF. (1998). *Textes portant réorganisation agraire et foncière au Burkina Faso*, Ouagadougou.

Ramesh, S. P. (1988). Artificial intelligence techniques for diagnostic reasoning in medicine. *In Exploring Artificial Intelligence: Survey talks from the National Conferences on Artificial Intelligence*. 347-379.

Ramm, J. F. (1992). A planning and training approach for local development in Madang Province, Papua New Guinea. In *UNCRD Working Paper*, Vol. 92, pp. 104.

Rasmussen, M. S. (1998). Developing simple, operational, consistent NDVI-vegetation models by applying environmental and climatic information. Part II. Crop yield assessment. *International Journal of Remote Sensing*, **19**(1), 119-139.

Reiter, R. (1987). A theory of diagnosis from first principles. *AI Journal*, **32**(1).

Renberg, A., and Paarup-Laursen, B. (1997). Determinants for land use strategies in a Sahelian agro-ecosystem. Anthropological and ecological aspects of natural resources management. *Agricultural Systems*, **53**, 209 -229.

Richards, J. A. (1993). *Remote sensing digital image analysis: an introduction*. Springer-Verlag, Berlin etc.

Rodriguez, P. O. P. (1995). Land use conflicts and planning strategies in urban fringes: a case study of western Caracas, Venezuela. PhD Thesis *Faculty of Sciences*, University of Ghent. Ghent, pp. 302.

Röling, N. G., and Wagemakers, M. A. E. (1998). A new practice: facilitating sustainable agriculture. In *Facilitating Sustainable Agriculture. Participator learning and adaptative management in times of environmental uncertainty*, (Eds) N. G. Roling, and M. A. E. Wagemakers, Cambridge University Press. Wageningen, pp. 3-22.

Roling, N. S. (1997). The soft side of land: socio-economic sustainability of land use systems. *ITC Journal*, **1997(3-4)**, 248-262.

Roy, S. B., Chatterjee, M., Yadav, G. Muherjee, R., and Bhattacharya, P. (1997). *Group sensitisation and participatory rural appraisal process. Documentation of training for Indian Foresters*. Inter-India Publications.

Ruben, R., Moll, H., Kuyvenhoven, A. (1998). Integrating agricultural research and policy analysis: Analytical framework and policy applications for bio-economic modelling. *Agricultural Systems*, **58**(3), 331-349.

Saaty, L. T., and Vargas, L.G. (2001). *Models, methods, concepts and applications of the analytic hierarchy process*. Kluwer Academic, Boston.

Schorlemer, D. (1997). Les methodologies de la gestion des terroirs: un exemple de projet realise au Burkina Faso. *Agriculture et Developpement Rural*, **1/97**, 8 - 14.

Scoones, I., and Thompson, J. (1994). Knowledge, power and agriculture: towards a theoretical understanding. In *Beyond farmer first: rural people's Knowledge, agricultural research and extension practice.* (Ed) I. Scoones, and J., Thompson. Intermediate Technology.

London. pp. 15 - 32.

Scoones, I., and Toulmin, C. (1998). Soil nutrient budgets and balances: What use for policy? *Agriculture, Ecosystems and Environment*, **71**(1-3), 255-267.

Sedogo, L. G., and Groten S. M.E. (2000). Definition of land management units for GIS support to participatory planning: A case study on participatory land management in Burkina Faso. *Canadian Journal of Development Studies*, **XXI**(Special Issue: Participatory Development), 523-542.

Shaner, W. W., Philipp, P.F., and Schmehl, W.R. (1982). *Farming systems research and development: Guidelines for developing countries*. Boulder, CO: Westview Press.

Shaxson, F., Tiffen, M., Wood, A., and Turton, C. (1997). Better land husbandry: Re-thinking approaches to land improvement and the conservation of water and soil. In *Natural Resource Perspectives*, Vol. 19, ODI. London UK, pp. 4.

Shephard, I., and Bell, S. (1989). Application of a systems development methodology in developing countries. *Information Technology for Development*, **4**(1), 61 - 72.

Sivakumar, M. V. K., and Gnoumou, F. (1987). *Agroclimatology of West Africa: Burkina Faso*, Patancheru, Andhra 502324, India.

Skidmore, A. K. (1989). An expert system classifies eucalypt forest types using Thematic Mapper data and a digital terrain model. *Photogrammetric Engineering and Remote Sensing*, **55**(10), 1449-1464.

Skidmore, A. K., Ryan, P.J., Dawes, W., Short, D., and O'Loughlin, E. (1991). Use of an expert system to map forest soils from a geographical information system. *International Journal of Geographical Information Systems*, **5**(4), 431-445.

Skidmore, A. K., Watford, F., Luckananurug, P., and Ryan, P.J. (1996). An operational GIS expert system for mapping forest soils. *Photogrammetric Engineering and Remote Sensing*, **62**(5), 501-511.

Skidmore, A. K., Bijker, W., Schmidt, K. S., and Kumar, L. (1997). Use of remote sensing and GIS for sustainable land management. *ITC Journal*, **3 / 4**, 302-315.

Smaling, E. M. A., Fresco, L., and De Jager, A. (1996). Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture. *Ambio*, **25/8**, 492-496.

Smaling, M. A. (1998). Nutrient Balances as indicators of productivity and sustainability in Sub-Saharan African agriculture: Papers presented during the conference: soil fertility management in Sub Saharan Africa: Nairobi. Kenya Agriculture. *Ecosystems & Environment*, **71**(1-3 special issues), 235.

Smyth, A. J., and Dumansky, J. (1993). *FESLM: An international framework for evaluating sustainable land management: a discussion paper*. FAO, Rome.

Sombroek, W. G., Anatoine, J. (1994). The use of geographic information systems (GIS) in land resources appraisal. *Outlook on Agriculture*, **23**(4), 249-255.

Stamm, V., and Sawadogo, J, P. (1995). Structures foncières et gestion des terroirs au Burkina Faso. In *Document de travail*, Vol. 12, CEDRES/LAVAL. Ouagadougou.

Stoorvogel, J. J., and Smaling, E.M.A. (1990). Assessment of soil nutrient depletion in Sub-Saharan Africa 1983-2000. The Winand Staring Centre for Integrated Land, Soil and water Research (SC-DLO). 28.

Stoorvogel, J. J., Smaling, E.M.A.and Janssen, B.H. (1993). Calculating soil nutrient balances in Africa at different scales: I Supra national scale. *Fertilizer Research*, **35**(3), 237-250.

Stroosnijder, L., and Rheenen, T. van. (2001). Agro-Sylvo-Pastoral land use in Sahelian Villages. In *Advances in ecology*, Vol. 33, IUSS. Wageningen, pp. 408.

Suryana, N. (1997). A geoinformation theoretical approach to inductive erosion modelling based on terrain mapping, PhD Thesis wageningen Agricultural University. Wageningen, pp. 234.

Szymanski, M., Whitewing, L., Colleti, J. (1998). The Use of PRA methodologies to link indigenous knowledge and use decision among the Winnebago tribe of Nebraska. *Indigenous*

knowledge and development monitor, **6**(2).
Tang, A. Y., Adams T.M., and Usery E.L. (1996). A spatial data model design for feature-based geographical information systems. *International Journal of Geographical Information Systems.* **10**(5), 643-659.
Tappan, G. G., Tyler, D. J., Wehde, M.E., and Moore, D.G. (1992). Monitoring rangeland dynamics in Senegal with advanced very high-resolution radiometer data. *Geocarto-International*, **7**(1), 87-98.
Teyssier, A. (1995). La gestion des terroirs: a review of a Francophone concept, and a case study of its application. *Rural Extension Bulletin*, **7**(4), 43 - 48.
Thieba, D., Ouedraogo, H., Mathieu, P. (1995). La gestion alternative des conflits lies aux ressources naturelles. Synthèses régionales. CILSS. FAO- FTPP.
Toledo, V. M. (1997). Sustainable development at the village community level: a third world perspective. In *Environmental Sustainability*, (Ed) F. Smith, St Lucie Press, pp. 233-250.
UNCED. (1992). Earth summit: convention on biological diversity. In *"United Nations Conference on Environment and Development UNCED"*, ed. U. Nations, United Nations. New York; Rio de Janeiro, Brazil.
UNDP-FAO. (1980). *Création d'un Service des Sols Haute Volta. Etat des connaissances des sols*. United Nation Development Program, Food and Agriculture Organisation (UNDP-FAO), Rome, Italy.
UNEP. (1997). Assessing soil degradation. FAO.
UNEP, F. (1995). Negotiating a sustainable future for the land. An integrated approach to the planning and management of land resources. Rome.
United Nations. (1996). *Manual on GIS for planners and decision makers*. Economic and Social Commission for Asia and the Pacific, New York.
UNSO. (1994). Gestion de Terroirs: Concept and Development. United Nations Sudano-Sahelian Office.
Upreti, B. R. (2001). Conflict management in natural resources. A study of land, water, and forest conflicts in Nepal. PhD Thesis Wageningen University. Wageningen, pp. 195.
Upton, M. (1987). *African farm management*. Cambridge University Press, Cambridge etc.
Vainio-Mattila, A. (2000). The Seduction and significance of participation for development interventions. *Canadian Journal of Development Studies*, **XXI**(Special issues: Participatory Development), 431- 446.
van den Briel, J., Schutof, P., and Topper, E. (1994). *L'Aménagement des terroirs Villageois: Contribution a la gestion durable des ressources naturelles. Une étude de cas du projet de reboisement Rive Droite Tera, Niger*. Université Agronomique, Wageningen.
van den Hoek, A. I. (1988). Land-Use Planning for social forestry: A Planning methodology at local Level for social forestry programmes on Java, Indonesia. In *Local level planning for sustainable land use*, (Eds). R. P. F. van Haeringen, and Wiersum, K. .F.
van den Hoek, A. I. (1992). Planning as a Learning process: a strategy for planning land use programmes at local level with special reference to the uplands of Java. PhD Thesis Wageningen Agricultural University. Wageningen, pp. 232.
van Diepen, C. A., Keulen, H. van, Wolf, J. and Berkhout, J.A.A. (1991). Land evaluation: from intuition to quantification. *Advances in Soil Sciences*, **15**, 139-204.
van Duivenbooden, N. (1997). Land-use system analysis, a multi-scale methodology to explore options for development of sustainable agricultural production system. *International conference on Geo-Information for sustainable land management. 17-21 August 1997*, Enschede.
van Keulen, H., van Ittersum, M. K., and de Ridder, N. (2000). New approaches to land use planning. In *Systems reaserch for optimizing future land use in South and Aoutheast Asia.* IRRI Vol. No 2(2000). Los Banaos, Philippines.

Verheye, W. H. (1997). Land use planning and national soil policies. *Agricultural Systems*, **No 53**, 161 - 174.

Walker, G. B., and Daniels, S. E. (1997). Foundations of natural resource conflict: Conflict theory and public policy. In *Conflict management and public participation in land management* S. EFT Proceeding No 14, (Eds) B. Solberg, and S. Mina. European Forest Institute, pp. 13 - 36.

Walker, M., and Sarkar, A. A. (1996). The development of a national agricultural extension policy in Bangladesh. *European Journal of Agricultural Education and Extension*, **3**(2), 85-95.

Warner, M., and Jones, P. S. O. (1998). *Assessing the need to manage conflict in community-based natural resource projects*. Overseas Development Institute (ODI), London; UK.

Warner, M. L. (2000). *Conflict management in community-based natural resource projects: Experiences from Fiji and Papua Guinea.* Overseas Development Institute (ODI), London; UK.

Waters-Bayer, A., and Bayer, W. (1994). *Planning with pastoralists: PRA and More*. Deutche Gesellsschaft fur Technische Zusammenarbelt (GTZ).

WCED. (1987). *Our Common Future*. World Commission on Environment and Development and Oxford University Press, Oxford, U.K.

Webster, C. J. (1994). Structured methods for GIS design. Part 1: a relational system for physical plan monitoring. *Computer Environment and Urban Systems*, **18**(1), 1 - 18.

Weiner, D., Trevor, M. H. and Craig, W. J. (2001). Community Participation and Geographic Information Systems. *Paper presented at the "ESF-NSF Workshop on Access to Geographic Information and Participatory Approaches Using Geographic Information",* Spoleto, 6-8 December 2001. *http://www.iapad.org/bibliography.htm*.

Wiersum, K. F. (1988). Local Level Planning for Sustainable Land Use: Introduction to the theme. In *Local level planning for sustainable land use*, (Eds) R. P. F. van Haerringen and K. F. Wiersum, Bos-Document.

Wischmeier, W. H., and Smith, D.D. (1978). Predicting rainfall erosion losses. A*gricultural hand book*. United States Department of Agriculture.

World Bank. Investing in Pastoralism: Sustainable natural Resources management in arid Africa and the Middle East. *World Bank technical Paper*, Vol. 365.

World-Bank. (1997). *Rural Development: From Vision to Action.* World Bank, Washington DC.

World Bank. (1997). Second National Agricultural Service Development Project. World Bank. 15730-BUR.

World Bank. (2000a). Burkina Faso: Community Based Rural Development (APL) Report No PID8358. World Bank.

World Bank. (2000b). *African development indicators*. The World Bank, Washington, D.C.

Yonli, P. E. (1997). Stratégies paysannes en matière de sécurité alimentaire et de commercialisation céréalière: Le rôle des banques de céréales dans le plateau central du Burkina Faso, University of Groningen. Groningen, pp. 229 pp.

Yoshitaka, K., and Hiroki, O. (1997). A Case Study of a Real-Time Problem Solving Strategy in an Air Traffic Control Problem. *Expert Systems with Applications*, **12**(1), 71-79.

Yue-Hong, C. (1997). *Exploring spatial analysis in geographic information systems*. OnWord Press, Santa Fe.

Zeeuw, F. d. (1997). Borrowing of land, security of tenure and sustainable land use in Burkina Faso. *Development and Change*, **28**(3), 583-595.

CURRICULUM VITAE

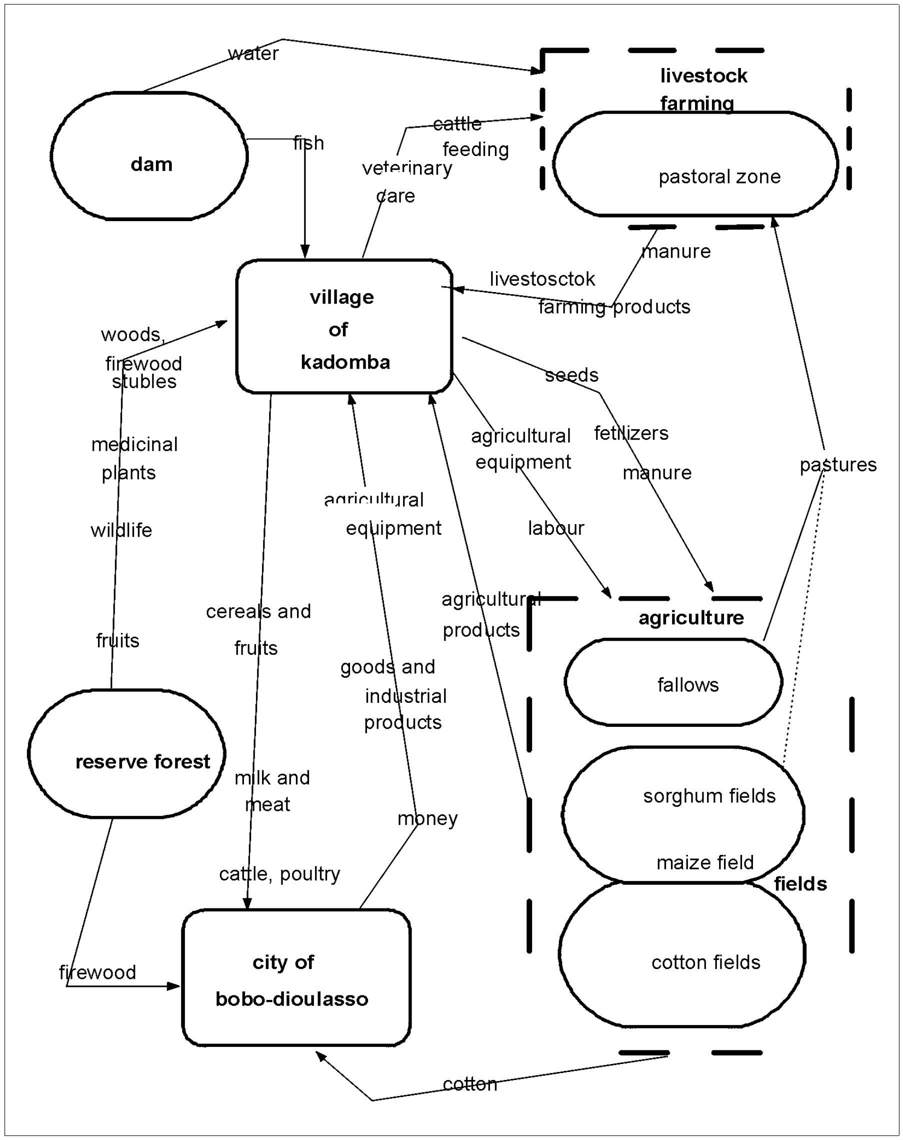
Laurent Gouinde Sedogo was born on the 15th of March 1956 in Arbinda, Province of Soum Burkina Faso. Between 1969 and 1976 he attended a secondary technical high school in Cote d'Ivoire. Between 1976 and 1978 he studied Mathematics and Physics at the University Mohamed V in Rabat (Morocco) and then specialized in land surveying and mapping in Morocco and France from 1978 to 1980.

He was employed as a land surveyor and as a teacher of topography and cartography for the national army of Burkina Faso as from September 1980. From 1984 to 1987 he occupied several high administrative and political positions and was among the pioneers who set up the national committee for desertification control in Burkina Faso. From 1988 to 1990, he was appointed as Minister of Farmers' Cooperatives. From 1991 to 1993 he was the manager of the desertification control program (LUCODEB) at the ministry of Environment.

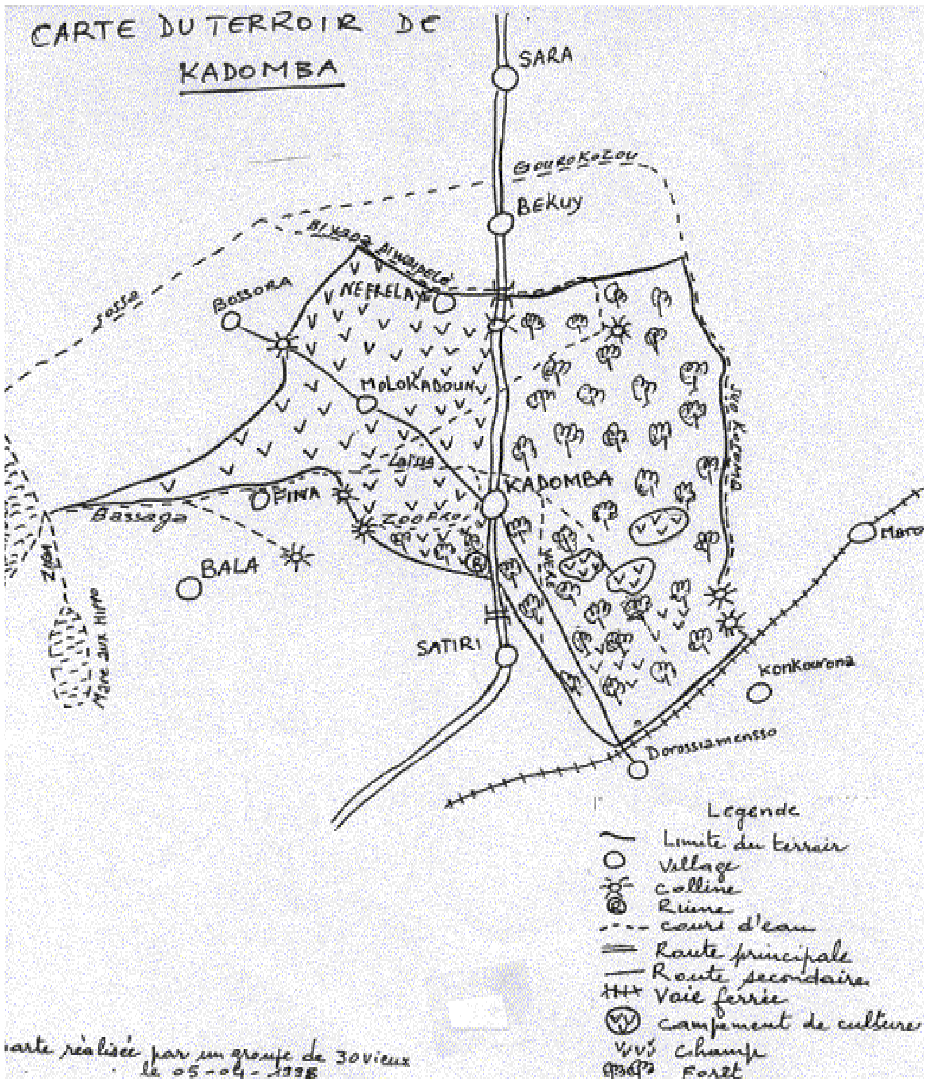
In 1993 he joined the International Institute for Aerospace Survey and Earth Sciences (ITC) where, jointly with the Wageningen Agricultural University he obtained his MSc degree in GIS for Rural Applications (GIR) in 1995. Back in his country he worked as GIS expert for the Ministry of Environment and the National Land Use Planning Program (PNGT). From August to December 1996 he attended a short course on Digital Image Processing (DIP5) at ITC and started his PhD studies in participatory land use planning and sustainable land management at ITC, Enschede, the Netherlands in September 1998.

APPENDIX A:

PARTICIPATORY RURAL APPRAISAL (PRA) DATA



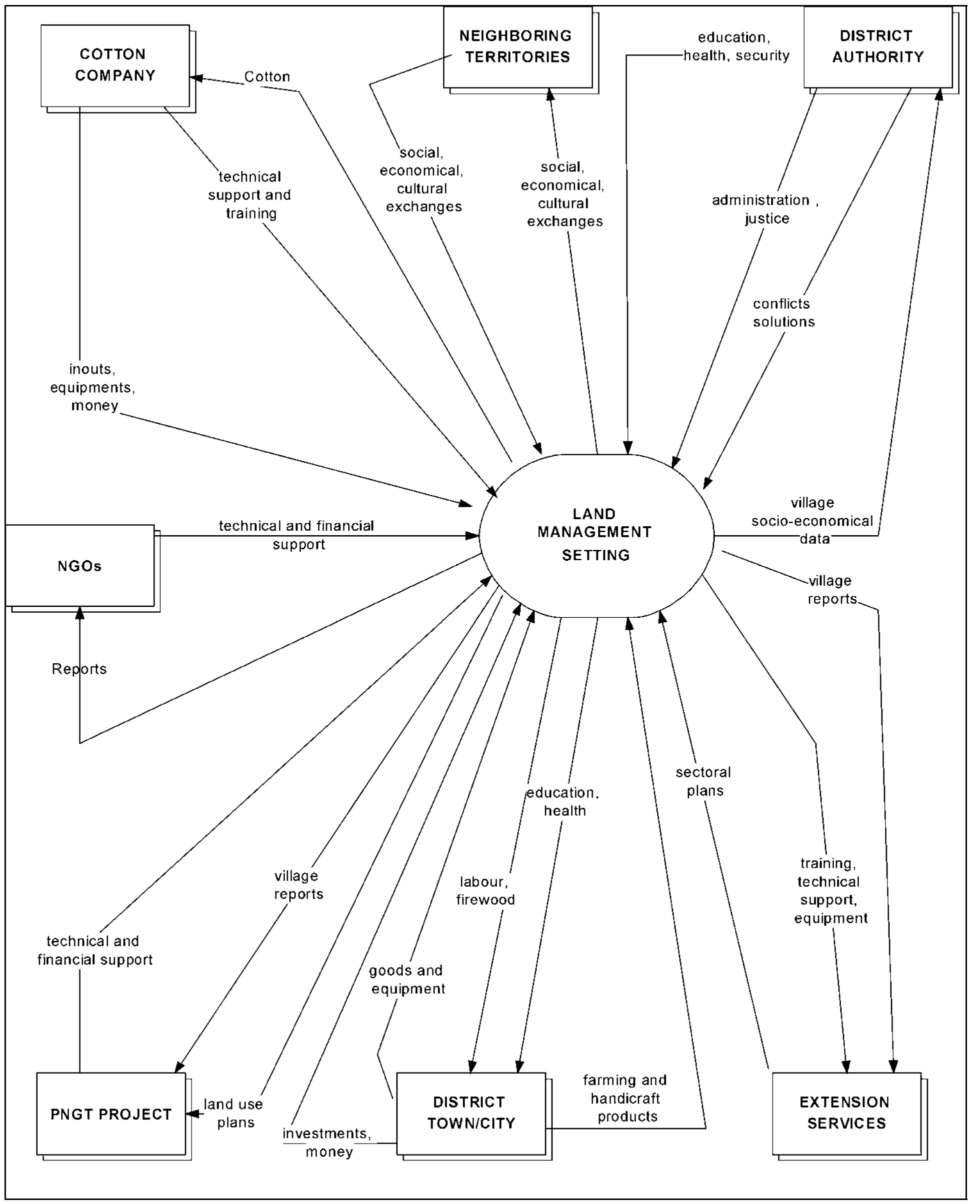
Digital reproduction of the diagram of production system drawn by a group of farmers in one village of the study area,



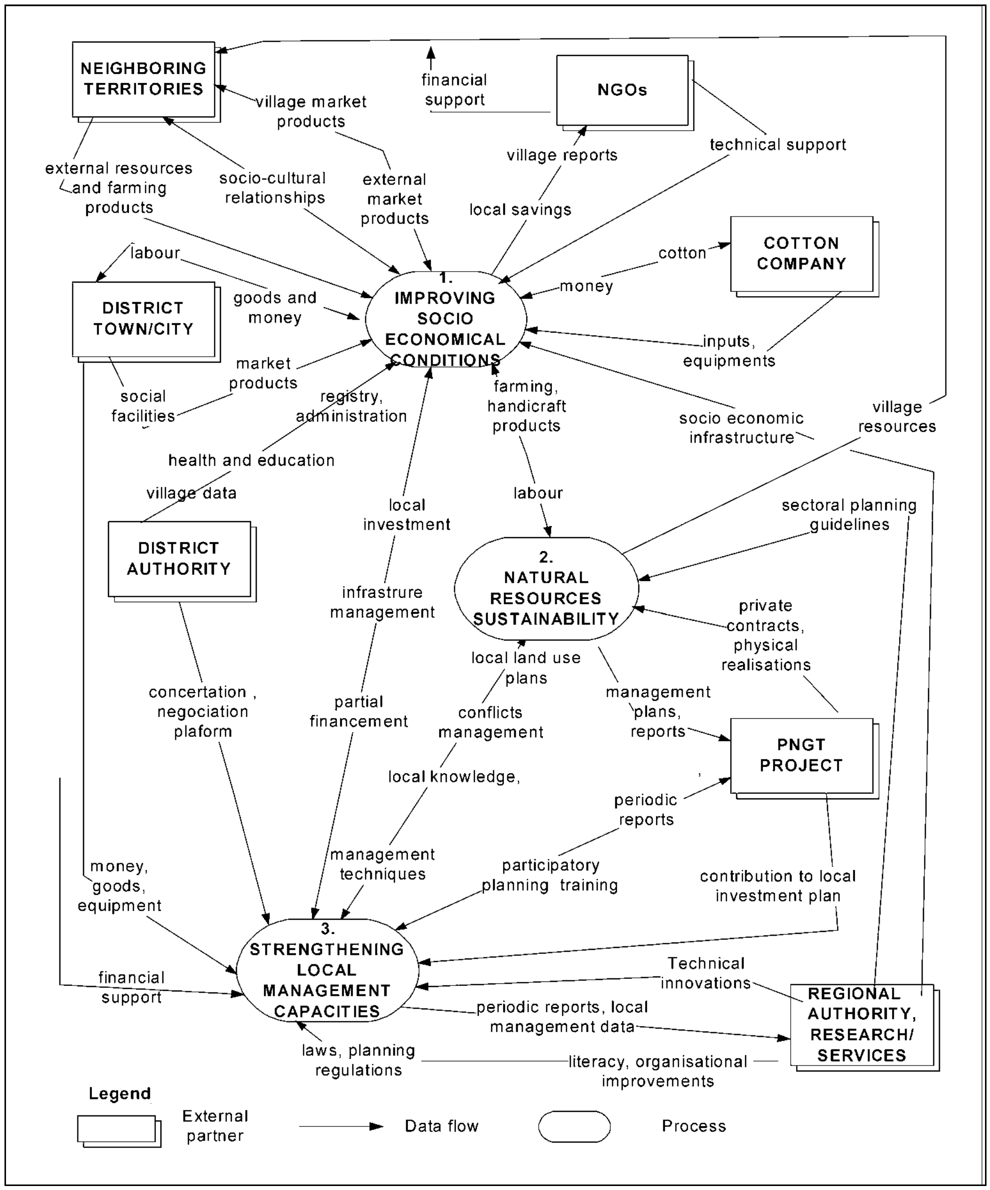
Sketch map of resources distribution drawn by the a group of elders in one village of the study area. N.B: Note that there is no scale

APPENDIX B:

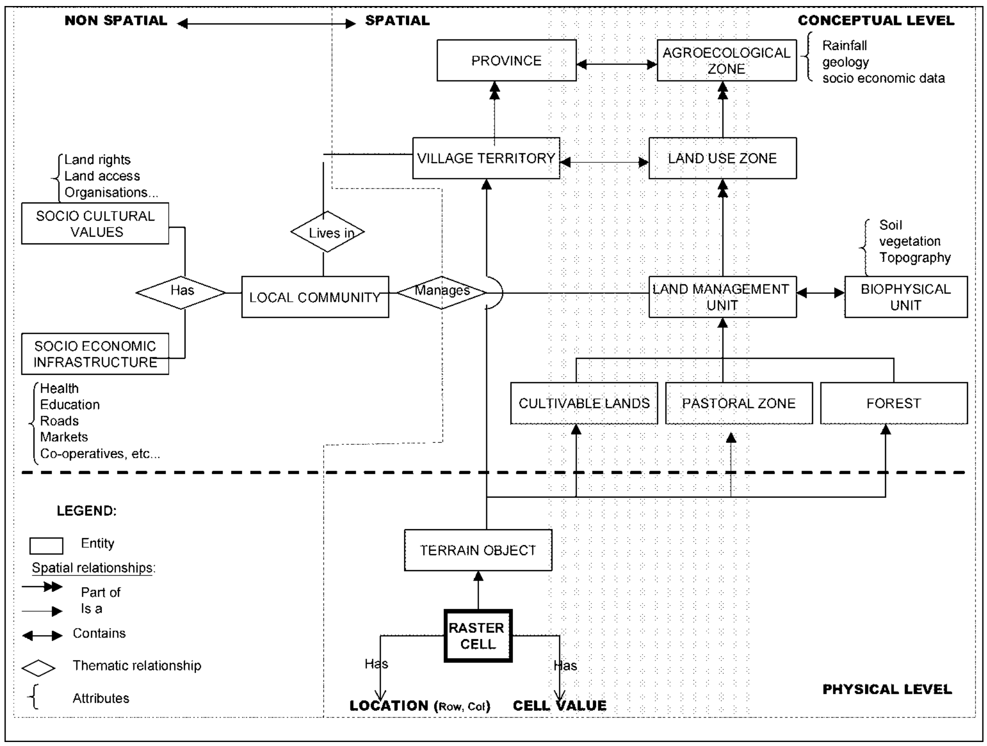
INFORMATION SYSTEM ANALYSIS AND DESIGN



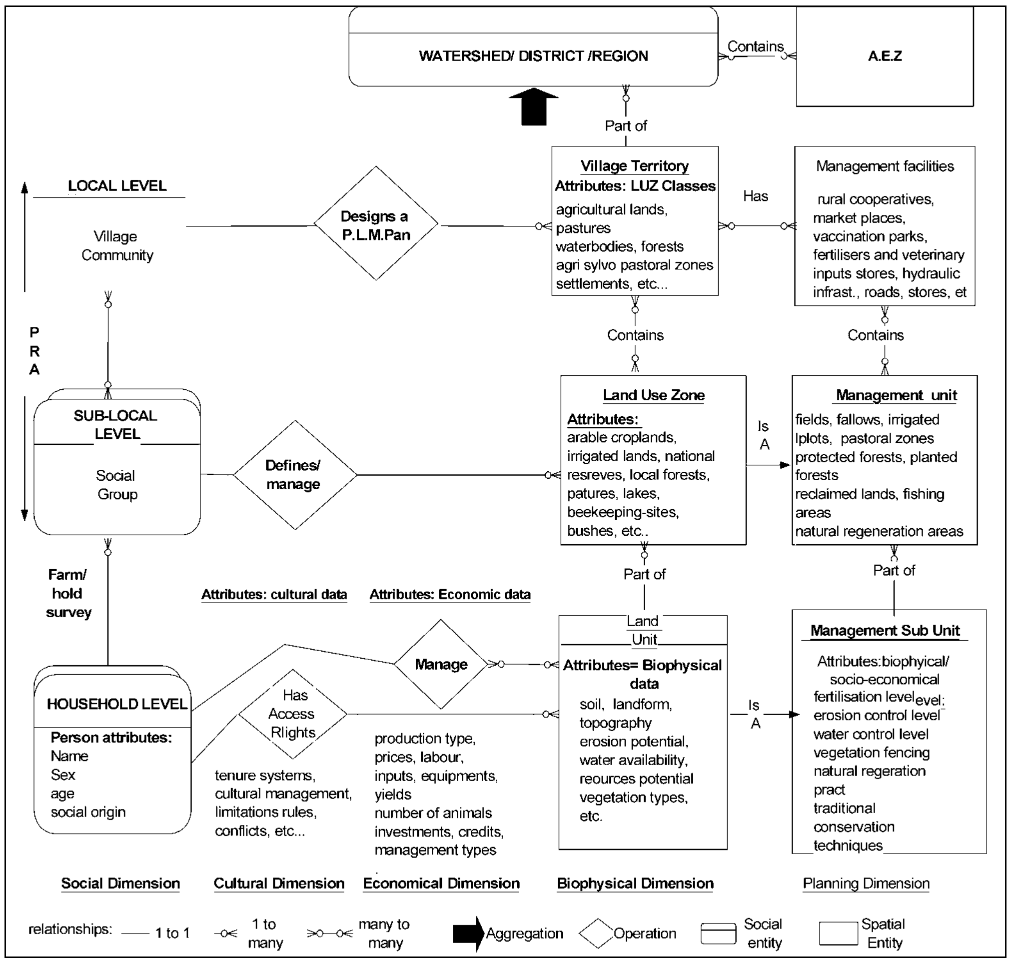
Kadomba Village Land management Information system: Context Diagram



Kadomba Village Land management Information system: Top Level Diagram



Conceptual Model Derived from a Formal Data Structure for Raster Maps (After Sedogo, 1995)



Logical Entity Relation Model for storing land management data in a GIS

APPENDIX C:

ITC DISSERTATION LIST

1. Akinyede, 1990, Highway cost modelling and route selection using a geotechnical information system
2. Pan He Ping, 1990, 90-9003757-8, Spatial structure theory in machine vision and applications to structural and textural analysis of remotely sensed images
3. Bocco Verdinelli, G., 1990, Gully erosion analysis using remote sensing and geographic information systems: a case study in Central Mexico
4. Sharif, M, 1991, Composite sampling optimization for DTM in the context of GIS
5. Drummond, J., 1991, Determining and processing quality parameters in geographic information systems
6. Groten, S., 1991, Satellite monitoring of agro-ecosystems in the Sahel
7. Sharifi, A., 1991, 90-6164-074-1, Development of an appropriate resource information system to support agricultural management at farm enterprise level
8. Zee, D. van der, 1991, 90-6164-075-X, Recreation studied from above: Air photo interpretation as input into land evaluation for recreation
9. Mannaerts, C., 1991, 90-6164-085-7, Assessment of the transferability of laboratory rainfall-runoff and rainfall - soil loss relationships to field and catchment scales: a study in the Cape Verde Islands
10. Ze Shen Wang, 1991: 90-393-0333-9, An expert system for cartographic symbol design
11. Zhou Yunxian, 1991, 90-6164-081-4, Application of Radon transforms to the processing of airborne geophysical data
12. Zuviria, M. de, 1992, 90-6164-077-6, Mapping agro-topoclimates by integrating topographic, meteorological and land ecological data in a geographic information system: a case study of the Lom Sak area, North Central Thailand
13. Westen, C. van, 1993, 90-6164-078-4, Application of Geographic Information Systems to landslide hazard zonation
14. Shi Wenzhong, 1994, 90-6164-099-7, Modelling positional and thematic uncertainties in integration of remote sensing and geographic information systems
15. Javelosa, R., 1994, 90-6164-086-5, Active Quaternary environments in the Philippine mobile belt
16. Lo King-Chang, 1994, 90-9006526-1, High Quality Automatic DEM, Digital Elevation Model Generation from Multiple Imagery
17. Wokabi, S., 1994, 90-6164-102-0, Quantified land evaluation for maize yield gap analysis at three sites on the eastern slope of Mt. Kenya
18. Rodriguez, O., 1995, Land Use conflicts and planning strategies in urban fringes: a case study of Western Caracas, Venezuela
19. Meer, F. van der, 1995, 90-5485-385-9, Imaging spectrometry & the Ronda peridotites
20. Kufoniyi, O., 1995, 90-6164-105-5, Spatial coincidence: automated database updating and data consistency in vector GIS
21. Zambezi, P., 1995, Geochemistry of the Nkombwa Hill carbonatite complex of Isoka District, north-east Zambia, with special emphasis on economic minerals
22. Woldai, T., 1995, The application of remote sensing to the study of the geology and structure of the Carboniferous in the Calañas area, pyrite belt, SW Spain
23. Verweij, P., 1995, 90-6164-109-8, Spatial and temporal modelling of vegetation patterns: burning and grazing in the Paramo of Los Nevados National Park,

Colombia

24. Pohl, C., 1996, 90-6164-121-7, Geometric Aspects of Multisensor Image Fusion for Topographic Map Updating in the Humid Tropics
25. Jiang Bin, 1996, 90-6266-128-9, Fuzzy overlay analysis and visualization in GIS
26. Metternicht, G., 1996, 90-6164-118-7, Detecting and monitoring land degradation features and processes in the Cochabamba Valleys, Bolivia. A synergistic approach
27. Hoanh Chu Thai, 1996, 90-6164-120-9, Development of a Computerized Aid to Integrated Land Use Planning (CAILUP) at regional level in irrigated areas: a case study for the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam
28. Roshannejad, A., 1996, 90-9009284-6, The management of spatio-temporal data in a national geographic information system
29. Terlien, M., 1996, 90-6164-115-2, Modelling Spatial and Temporal Variations in Rainfall-Triggered Landslides: the integration of hydrologic models, slope stability models and GIS for the hazard zonation of rainfall-triggered landslides with examples from Manizales, Colombia
30. Mahavir, J., 1996, 90-6164-117-9, Modelling settlement patterns for metropolitan regions: inputs from remote sensing
31. Al-Amir, S., 1996, 90-6164-116-0, Modern spatial planning practice as supported by the multi-applicable tools of remote sensing and GIS: the Syrian case
32. Pilouk, M., 1996, 90-6164-122-5, Integrated modelling for 3D GIS
33. Duan Zengshan, 1996, 90-6164-123-3, Optimization modelling of a river-aquifer system with technical interventions: a case study for the Huangshui river and the coastal aquifer, Shandong, China
34. Man, W.H. de, 1996, 90-9009-775-9, Surveys: informatie als norm: een verkenning van de institutionalisering van dorp - surveys in Thailand en op de Filippijnen
35. Vekerdy, Z., 1996, 90-6164-119-5, GIS-based hydrological modelling of alluvial regions: using the example of the Kisaföld, Hungary
36. Pereira, Luisa, 1996, 90-407-1385-5, A Robust and Adaptive Matching Procedure for Automatic Modelling of Terrain Relief
37. Fandino Lozano, M., 1996, 90-6164-129-2, A Framework of Ecological Evaluation oriented at the Establishment and Management of Protected Areas: a case study of the Santuario de Iguaque, Colombia
38. Toxopeus, B., 1996, 90-6164-126-8, ISM: an Interactive Spatial and temporal Modelling system as a tool in ecosystem management: with two case studies: Cibodas biosphere reserve, West Java Indonesia: Amboseli biosphere reserve, Kajiado district, Central Southern Kenya
39. Wang Yiman, 1997, 90-6164-131-4, Satellite SAR imagery for topographic mapping of tidal flat areas in the Dutch Wadden Sea
40. Asun Saldana-Lopez, 1997, 90-6164-133-0, Complexity of soils and Soilscape patterns on the southern slopes of the Ayllon Range, central Spain: a GIS assisted modelling approach
41. Ceccarelli, T., 1997, 90-6164-135-7, Towards a planning support system for communal areas in the Zambezi valley, Zimbabwe; a multi-criteria evaluation linking farm household analysis, land evaluation and geographic information

systems

42. Peng Wanning, 1997, 90-6164-134-9, Automated generalization in GIS
43. Lawas, C., 1997, 90-6164-137-3, The Resource Users' Knowledge, the neglected input in Land resource management: the case of the Kankanaey farmers in Benguet, Philippines
44. Bijker, W., 1997, 90-6164-139-X, Radar for rain forest: A monitoring system for land cover Change in the Colombian Amazon
45. Farshad, A., 1997, 90-6164-142-X, Analysis of integrated land and water management practices within different agricultural systems under semi-arid conditions of Iran and evaluation of their sustainability
46. Orlic, B., 1997, 90-6164-140-3, Predicting subsurface conditions for geotechnical modelling
47. Bishr, Y., 1997, 90-6164-141-1, Semantic Aspects of Interoperable GIS
48. Zhang Xiangmin, 1998, 90-6164-144-6, Coal fires in Northwest China: detection, monitoring and prediction using remote sensing data
49. Gens, R., 1998, 90-6164-155-1, Quality assessment of SAR interferometric data
50. Turkstra, J., 1998, 90-6164-147-0, Urban development and geographical information: spatial and temporal patterns of urban development and land values using integrated geo-data, Villaviciencia, Colombia
51. Cassells, C., 1998, Thermal modelling of underground coal fires in northern China
52. Naseri, M., 1998, 90-6164-195-0, Characterization of Salt-affected Soils for Modelling Sustainable Land Management in Semi-arid Environment: a case study in the Gorgan Region, Northeast, Iran
53. Gorte B.G.H., 1998, 90-6164-157-8, Probabilistic Segmentation of Remotely Sensed Images
54. Tenalem Ayenew, 1998, 90-6164-158-6, The hydrological system of the lake district basin, central main Ethiopian rift
55. Wang Donggen, 1998, 90-6864-551-7, Conjoint approaches to developing activity-based models
56. Bastidas de Calderon, M., 1998, 90-6164-193-4, Environmental fragility and vulnerability of Amazonian landscapes and ecosystems in the middle Orinoco river basin, Venezuela
57. Moameni, A., 1999, Soil quality changes under long-term wheat cultivation in the Marvdasht plain, South-Central Iran
58. Groenigen, J.W. van, 1999, 90-6164-156-X, Constrained optimisation of spatial sampling: a geostatistical approach
59. Cheng Tao, 1999, 90-6164-164-0, A process-oriented data model for fuzzy spatial objects
60. Wolski, Piotr, 1999, 90-6164-165-9, Application of reservoir modelling to hydrotopes identified by remote sensing
61. Acharya, B., 1999, 90-6164-168-3, Forest biodiversity assessment: A spatial analysis of tree species diversity in Nepal
62. Akbar Abkar, Ali, 1999, 90-6164-169-1, Likelihood-based segmentation and classification of remotely sensed images
63. Yanuariadi, T., 1999, 90-5808-082-X, Sustainable Land Allocation: GIS-based decision support for industrial forest plantation development in Indonesia

64. Abu Bakr, Mohamed, 1999, 90-6164-170-5, An Integrated Agro-Economic and Agro-Ecological Framework for Land Use Planning and Policy Analysis
65. Eleveld, M., 1999, 90-6461-166-7, Exploring coastal morphodynamics of Ameland (The Netherlands) with remote sensing monitoring techniques and dynamic modelling in GIS
66. Yang Hong, 1999, 90-6164-172-1, Imaging Spectrometry for Hydrocarbon Microseepage
67. Mainam, Félix, 1999, 90-6164-179-9, Modelling soil erodibility in the semiarid zone of Cameroon
68. Bakr, Mahmoud, 2000, 90-6164-176-4, A Stochastic Inverse-Management Approach to Groundwater Quality
69. Zlatanova, Z., 2000, 90-6164-178-0, 3D GIS for Urban Development
70. Ottichilo, Wilber K., 2000, 90-5808-197-4, Wildlife Dynamics: An Analysis of Change in the Masai Mara Ecosystem
71. Kaymakci, Nuri, 2000, 90-6164-181-0, Tectono-stratigraphical Evolution of the Cankori Basin (Central Anatolia, Turkey)
72. Gonzalez, Rhodora, 2000, 90-5808-246-6, Platforms and Terraces: Bridging participation and GIS in joint-learning for watershed management with the Ifugaos of the Philippines
73. Schetselaar, Ernst, 2000, 90-6164-180-2, Integrated analyses of granite-gneiss terrain from field and multisource remotely sensed data. A case study from the Canadian Shield
74. Mesgari, Saadi, 2000, 90-3651-511-4, Topological Cell-Tuple Structure for Three-Dimensional Spatial Data
75. Bie, Cees A.J.M. de, 2000, 90-5808-253-9, Comparative Performance Analysis of Agro-Ecosystems
76. Khaemba, Wilson M., 2000, 90-5808-280-6, Spatial Statistics for Natural Resource Management
77. Shrestha, Dhruba, 2000, 90-6164-189-6, Aspects of erosion and sedimentation in the Nepalese Himalaya: highland-lowland relations
78. Asadi Haroni, Hooshang, 2000, 90-6164-185-3, The Zarshuran Gold Deposit Model Applied in a Mineral Exploration GIS in Iran
79. Raza, Ale, 2001, 90-3651-540-8, Object-oriented Temporal GIS for Urban Applications
80. Farah, Hussein, 2001, 90-5808-331-4, Estimation of regional evaporation under different weather conditions from satellite and meteorological data. A case study in the Naivasha Basin, Kenya
81. Zheng, Ding, 2001, 90-6164-190-X, A Neural - Fuzzy Approach to Linguistic Knowledge Acquisition and Assessment in Spatial Decision Making
82. Sahu, B.K., 2001, Aeromagnetics of continental areas flanking the Indian Ocean; with implications for geological correlation and Gondwana reassembly
83. Alfestawi, Y., 2001, 90-6164-198-5, The structural, paleogeographical and hydrocarbon systems analysis of the Ghadamis and Murzuq Basins, West Libya, with emphasis on their relation to the intervening Al Qarqaf Arch
84. Liu, Xuehua, 2001, 90-5808-496-5, Mapping and Modelling the Habitat of Giant Pandas in Foping Nature Reserve, China

85. Oindo, Boniface Oluoch, 2001, 90-5808-495-7, Spatial Patterns of Species Diversity in Kenya
86. Carranza, Emmanuel John, 2002, 90-6164-203-5, Geologically-constrained Mineral Potential Mapping
87. Rugege, Denis, 2002, 90-5808-584-8, Regional Analysis of Maize-Based Land Use Systems for Early Warning Applications
88. Liu, Yaolin, 2002, 90-5808-648-8, Categorical Database Generalization in GIS
89. Ogao, Patrick, 2002, 90-6164-206-X, Exploratory Visualization of Temporal Geospatial Data using Animation
90. Abadi, Abdulbaset M., 2002, 90-6164-205-1, Tectonics of the Sirt Basin – Inferences from tectonic subsidence analysis, stress inversion and gravity modelling
91. Geneletti, Davide, 2002, 90-5383-831-7, Ecological Evaluation for Environmental Impact Assessment