

University of Groningen

Combining interactive multiple goal linear programming with an inter-stakeholder communication matrix to generate land use options

Nidumolu, Uday Bhaskar; Keulen, Herman van; Lubbers, Marcel; Mapfumo, Andrew

Published in:
Environmental Modelling & Software

DOI:
[10.1016/j.envsoft.2005.11.004](https://doi.org/10.1016/j.envsoft.2005.11.004)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2007

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Nidumolu, U. B., Keulen, H. V., Lubbers, M., & Mapfumo, A. (2007). Combining interactive multiple goal linear programming with an inter-stakeholder communication matrix to generate land use options. *Environmental Modelling & Software*, 22(1), 73. <https://doi.org/10.1016/j.envsoft.2005.11.004>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Combining interactive multiple goal linear programming with an inter-stakeholder communication matrix to generate land use options

Uday Bhaskar Nidumolu ^{a,*}, Herman van Keulen ^b, Marcel Lubbers ^c, Andrew Mapfumo ^a

^a Department of Natural Resources, International Institute for Geoinformation Science and Earth Observation (ITC), Enschede, The Netherlands

^b Plant Research International/Group Plant Production Systems, Plant Sciences Group, Wageningen University and Research Centre, PO Box 16, 6700 AA Wageningen, The Netherlands

^c Group Plant Production Systems, Wageningen University and Research Centre, PO Box 430, 6700 AK Wageningen, The Netherlands

Received 26 April 2005; received in revised form 8 November 2005; accepted 17 November 2005

Available online 7 February 2006

Abstract

An Interactive Multiple Goal Linear Programming (IMGLP) model is developed that considers objectives of multiple stakeholders, i.e. different farmer groups, district agricultural officers and agricultural scientists for agricultural land use analysis. The analysis focuses on crop selection; considering irrigated and non-irrigated crops such as rice, sugarcane, sorghum, cotton, millet, pulses and groundnut. Interests of the most important stakeholders, farmers, policy makers and water users association are investigated. Important objectives of the farmers are increased income and retaining paddy area; of the policy makers (Agricultural Department) increased farmers' income, maintaining rural employment, improve water-use efficiency, reduce fertiliser and biocide use and discourage farmers from cultivating marginal lands; of the water users association optimising water use. Scenarios have been constructed by combining objectives and constraints. A Stakeholder Communication Matrix (SCM) indicating the level of communication and information flow among stakeholders in the district was generated after a Participatory Rural Appraisal (PRA). Results of the scenarios generated with the IMGLP model were compared with the matrix. The relevance of analysing the results of the scenarios generated with the IMGLP model in the context of the SCM is illustrated for a sample set of scenarios. Scenario 1 (S1), where both the paddy area and the agricultural area are retained at the current level, is preferred by the farmers. However, the Agricultural Department would identify more easily with S10 in which the paddy area is reduced by 50% and the agricultural area by 20%, in accordance with the policy of limiting the area of high water-demanding crops and dissuading farmers from cultivating marginal lands, while the water users association would prefer S12, where water use is minimised by expanding the area of crops that are relatively less water-demanding. Income in S12 is 22% lower than in S1, while water use is 36% lower, and there is a significant reduction in biocide use. The conflict between S1 and S10 is compounded by the fact that communication between small-scale farmers and the Agricultural Department is relatively weak. Analysing the scenarios in the context of the SCM is useful to gain insight into the interactions among stakeholders in the system and take curative measures if required for improved communication. While the IMGLP model considers the bio-economics of the land use system, the SCM describes its social aspects, which may be critical for successful implementation of the IMGLP model.

© 2005 Published by Elsevier Ltd.

Keywords: Interactive Multiple Goal Linear Programming (IMGLP); Stakeholder communication matrix; Crop selection modelling; Scenarios

1. Introduction

Traditional land use analysis approaches have relied heavily on land evaluation and land suitability models.

However, as decisions on land use are co-determined by social and economic criteria, information on biophysical suitability alone is not sufficient for land use planning (Huizing and Bronsveld, 1994). In situations where many different (groups of) stakeholders have an active interest in the way the land is (being, or going to be) used, new methodologies for land use studies are required as a basis for formulation of land use policies. In these methodologies, the aims and aspirations of the different stakeholders have to be taken into

* Corresponding author. Current address: Pole Elevage, 7, Chemin L'Irat, Ligne Paradis, CIRAD Reunion, St Pierre 97410 Reunion (France). Tel.: +262 262 499288.

E-mail address: uday-bhaskar.nidumolu@cirad.fr (U.B. Nidumolu).

account, but they should be based on thorough knowledge of the agro-technical possibilities and socio-economic conditions under which land use has to take place (Van Keulen et al., 2002). Several studies have been reported on participatory land use planning: Hahn (1998) on the community land management (CLM) approach for land conflict management through participatory processes in Burkina Faso; Integrated Catchment Management (ICM) as a stakeholder-oriented approach for natural resources management in Australia (Queensland Government, 1991); Hagman and Murwira (1994) on participatory approaches for soil and water conservation in southern Zimbabwe; a number of case studies across the world have been listed by the World Summit on Sustainable Development focusing on the role of participation in planning and decision making as critical for success in sustainable development (WSSD, 2002); Reddy and Rao (1999), Sarma (1999), Srivastava (1999) and Yugandhar et al. (1999) give elaborate and critical evaluations of the watershed management, land use planning and participation process operational in India; Bojórquez-Tapia et al. (2001) on a GIS based approach for participatory decision making and land suitability assessment. The theoretical underpinnings of the use of a systems approach combined with participatory methods for water basin management are treated by Tippett (2005), while Mustajoki et al. (2004) illustrate stakeholder involvement in arriving at a consensus solution for environmental problems.

Agricultural policies aim at directing agricultural development in such a way that it leads to attaining a number of socio-economic goals. These include increased production, employment and profit, but also other goals such as environmental sustainability, pollution abatement and political compensation. A feasible development objective must consider all these goals imposed on a region (De Wit et al., 1988). Such regional land use systems (with their agro-ecological–social dimensions or functions) are complex and therefore difficult to model, and no blueprint solution exists for the best use of agricultural land under multiple development goals. Policy makers have to consider different policy options and at the same time learn-by-doing (Holling et al., 1998). As learning-by-doing is time-consuming and experiments are costly or may be impossible, the use of models may be helpful in reducing cost and time. By carefully analysing the results of targeted computer experiments, such models increase insight into the dynamics of these complex systems (Struif Bontkes and van Keulen, 2003). The models should present the results in such a way that possibilities and limitations, relationships and interdependencies become explicit (Zander and Kächele, 1999). It is especially important to identify conflicting goals and to explicitly quantify the trade-offs among the multiple goals that contribute to sustainable agriculture (Romero and Rehman, 1989; Van Kooten, 1993). One such modelling technique is Interactive Multiple Goal Linear Programming (IMGLP) that has been widely used to integrate different types of information and to generate land use options (De Wit et al., 1988; Van Keulen, 1990; Rabbinge and van Latesteijn, 1992; Chuvieco, 1993; Van Keulen et al., 1998; Van Ittersum et al., 1998; Zander and Kächele, 1999; Sujith Kumar et al., 2001; Sarkar and

Quaddus, 2002; Hengsdijk and van Ittersum, 2002; Lu et al., 2002, 2004; Dogliotti, 2003; Kaur et al., 2004). In environmental applications, IMGLP and fuzzy linear programming methods integrated with Life Cycle Assessment approach have recently been reported (Najm and El-Fadel, 2005; Tan, 2005).

The IMGLP model is expected to be applied as a negotiation support tool and communication is critical in negotiations. As land use is dynamic and co-determined by socio-economic conditions, it is important to understand the relationship between socio-economic conditions and land use to be able to adjust socio-economic conditions in a way that allows land users to make the right strategic, tactical and operational decisions at each point in time (Ganzert, 1995, as cited in Zander and Kächele, 1999). This requires communication and is only attainable if some kind of institutionalised driving force for sustainable development can be established (Röling, 1994). While various studies have used IMGLP as a modelling tool for land use analysis, an ‘explicit’ combination with Stakeholder Analysis (SA; though there is an implicit association with SA), defined as “an approach and procedure for gaining an understanding of a system by means of identifying the key actors or stakeholders in the system, and assessing their respective interests in that system” (Grimble et al., 1994), has not been reported, nor has the use of a Stakeholder Communication Matrix (SCM) as a means of identifying bottlenecks in acceptance of the IMGLP output. In formulating land use policies, many stakeholders at different levels are involved, e.g., small and large farmers, planning and enforcement officials and policy makers, each with their own ‘agenda’, but with the overall objective of the ‘development’ of a particular area. Stakeholders do not live in isolation but in a society, they communicate and share information on issues related to development, in this instance agricultural development, as the study focuses on agricultural land use. For an IMGLP model to be effective, a negotiated option should be selected. Arriving at such a broadly acceptable option requires mutual trust among the various stakeholders that can be built on the basis of understanding of their relationships as expressed in their communication and interactions. Such understanding will assist in identifying bottlenecks in communication, and analysing the reasons and eventually removing them. We argue that the options generated with an IMGLP model can be effectively implemented only on the basis of transparent negotiation, based on communication and information-sharing among various stakeholders, i.e. platform building. To describe the relations among the various stakeholders explicitly, a Stakeholder Communication Matrix (SCM) has been developed. The SCM illustrates the relationships among the different stakeholders in the area with communication and information-sharing as important indicators. The stakeholder communication context is important, because the SCM facilitates identification of possible bottlenecks in information-sharing (that may be the result of, for instance, power relations) that may lead to bias in assessment of the ‘weight’ of the objectives of various stakeholders, while a broad understanding of the attitudes of these stakeholders towards the outcome of the IMGLP model is necessary. For example, if objectives among stakeholders are conflicting, strong

communication links among them may facilitate finding a solution. However, if these communication links are relatively weak, strengthening these communication channels may be a pre-requisite for effective implementation of the IMGLP results. In a land use analysis cycle (Van Ittersum et al., 2004) that schematically represents the different phases in the process aiming at land use change, IMGLP analysis can be considered a discussion phase with participation of the stakeholders involved. The stakeholder communication matrix is a useful analytical tool for identifying and assessing the significance of conflicts of interest and cooperation and as a way of analysing the need for information-sharing among the different stakeholders (Grimble and Wellard, 1997). While IMGLP serves as a quantitative modelling tool, SCM represents qualitative information, reflecting the interactions among the various stakeholders.

The study reported in this paper has been conducted in the context of a large land use planning programme initiated by the Government of India called the ‘Integrated Mission for Sustainable Development (IMSD)’, covering about 83 million hectares spread across the country. Output of the project comprises land and water management ‘action plans’, to be implemented by District level resource managers. Databases on biophysical characteristics, such as soils, terrain, land cover and groundwater are available at 1:50 000 scale along with land suitability data (NRSA, 1995; Nidumolu and Alanga, 2001; Harmsen and Nidumolu, 2002; Nidumolu et al., 2004). The main objective of the current study is development of an IMGLP model and its integration with an SCM as a support tool in negotiating policies for sustainable crop production for the study area by various stakeholders.

2. Study area

The study area is Pitlam Mandal (mandal is an administrative block within a District), Nizamabad District, Andhra Pradesh State in India (Fig. 1), with an area of 18 214 ha. The

Table 1

Irrigated area (ha) by source and crop type and areal extent (%) in Kharif and Rabi seasons (CPO, 2001)

Season	Kharif	Rabi
Irrigation source		
Canal	69	0
Tanks	1100	564
Tube wells	1341	1612
Dugwells	130	22
Lift irrigation	244	201
Crop type		
Paddy	2709	1053
Jowar (pearl millet)	368	1225
Pulses	1945	173
Sugarcane	348	282
Groundnut	73	654
Cotton	539	0

population in the area, which is predominantly rural, is 41 847 according to the 2001 census. The major land cover categories are agriculture (10 114 ha), forests (3811 ha) and wastelands (3380 ha). Water bodies constitute the remaining area of 909 ha. Annual average rainfall is about 990 mm. Of the farmers’ holdings, 96% is less than 2 ha (small- and marginal-scale farmers; FAO, 2002). This category of farmers owns about 81% of the agricultural area, the remainder being owned by farmers with holdings exceeding 4 ha (medium- to large-scale farmers). Two distinct agricultural seasons can be distinguished: Kharif – rainy season between June and October and Rabi – post-rainy season from November to March. In Kharif, 2884 ha (out of 6170 ha, constituting both rainfed and irrigated) have irrigation facilities and in Rabi 2399 ha (out of 3944 ha, predominantly irrigated). Tanks and tube wells constitute the majority of the irrigation sources (Table 1). Paddy rice is the dominant crop with about 2700 ha cultivated in Kharif and about 1000 ha in Rabi. Sorghum (*Sorghum bicolor* (L.) Moench), green gram (*Vigna radiata*), black gram (*Vigna*

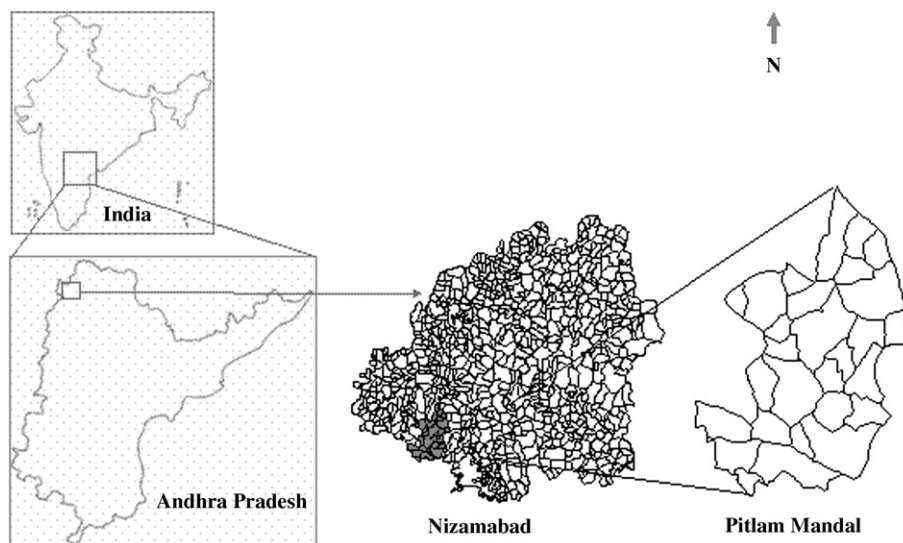


Fig. 1. Location of the study area.

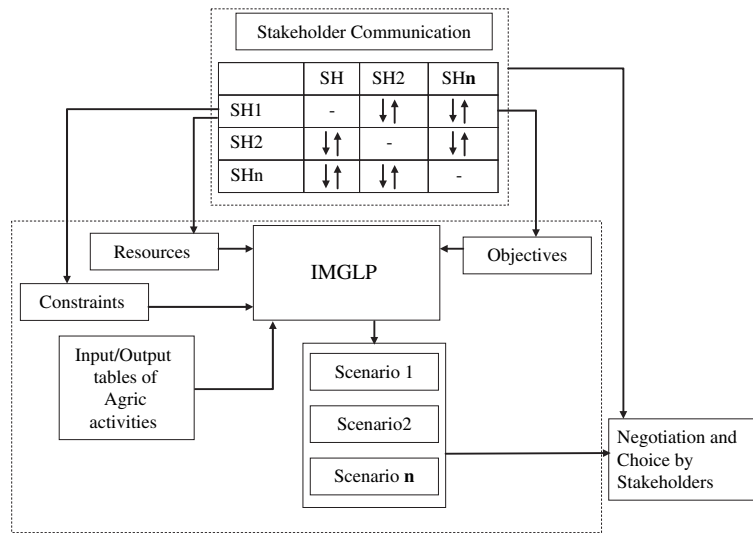


Fig. 2. Conceptual model of the combined analysis of IMGLP and stakeholder communication matrix.

mungo), sugarcane, cotton and groundnut constitute the other crops (Table 1).

3. Methodology

The conceptual model applied in the study is presented in Fig. 2. First, we conducted a stakeholder analysis and developed the Stakeholder Communication Matrix (SCM) based on interviews with individual stakeholders. SCM provides a framework for identification of possible bottlenecks in communication among stakeholders. Second, we developed an IMGLP model. The technical coefficients, describing a set of agricultural activities, were derived from published statistics of the area, surveys, expert knowledge and stakeholder input. Moreover, resources and constraints were defined. The stakeholders identified the objectives, from which through different combinations, a number of scenarios can be generated. The degree of acceptability of these scenarios by the various stakeholders depends on their level of communication. Hence, we combined the IMGLP and stakeholder communication matrix to identify possible bottlenecks in the adoption of the results of the IMGLP model scenarios.

4. SCM development

Stakeholder analysis is a powerful tool in policy analysis and formulation, and has considerable potential in natural resource policy and programme development. It has been developed in response to the challenge of multiple interests and objectives, and particularly the search for efficient, equitable and environmentally sustainable development strategies (Grimble and Wellard, 1997). Stakeholder analysis aims at analysing how stakeholders interrelate, what “hats” they may wear, and what networks exist (Ramirez, 1999). For the effectiveness of agricultural policy implementation, information-sharing is an important factor. Understanding of patterns, relationships and context of interactions among stakeholders is

one of the key steps in stakeholder analysis. The study analyses the type of information that is shared among the stakeholders and how the information flows. In the study area, the relations among stakeholders are complex, with the farmer who is the primary stakeholder, at the centre of attention. Fig. 3 shows how the stakeholders relate to each other, in terms of information-sharing and lines of command within the land use sector at regional level.

The stakeholders involved in the negotiations range from small farmers to District agricultural officials (Fig. 3). For the negotiations to be successful, effective communication among the various stakeholders is an absolute necessity. To assess the current relations among the various stakeholders, with emphasis on communication and information-sharing, an SCM was developed, on the basis of a stakeholder analysis in the study area over a period of several months during 2002–2003. Sixteen stakeholder(s) categories were distinguished, i.e. small/medium-scale farmers, large-scale farmers, village secretary, mandal officer, district planning officer, water users association, farmers training centre, agricultural officer, deputy and joint directors of agriculture, agricultural research station, agricultural market committee, District Rural Development Agency, district technology transfer advisory board, national banks and the national bank for agricultural and rural development.

In this study, the SCM (Fig. 4; the larger the circle, the more intensive the interaction) illustrating the way in which the stakeholders interact, and the intensity of interaction, has been used as a way of analysing the subjects and mode of information-sharing among stakeholders. For this purpose, we interviewed the 16 (groups of) stakeholders, using different methods: brainstorming to generate ideas among the farmers, followed by interviews with farmers and other stakeholders, using semi-structured questionnaires. Such questionnaires, which may restrict certain forms of communication, allow freedom in discussing certain topics and provide therefore options for in-depth exploration of various issues with respondents. The questions focused on key interests of the

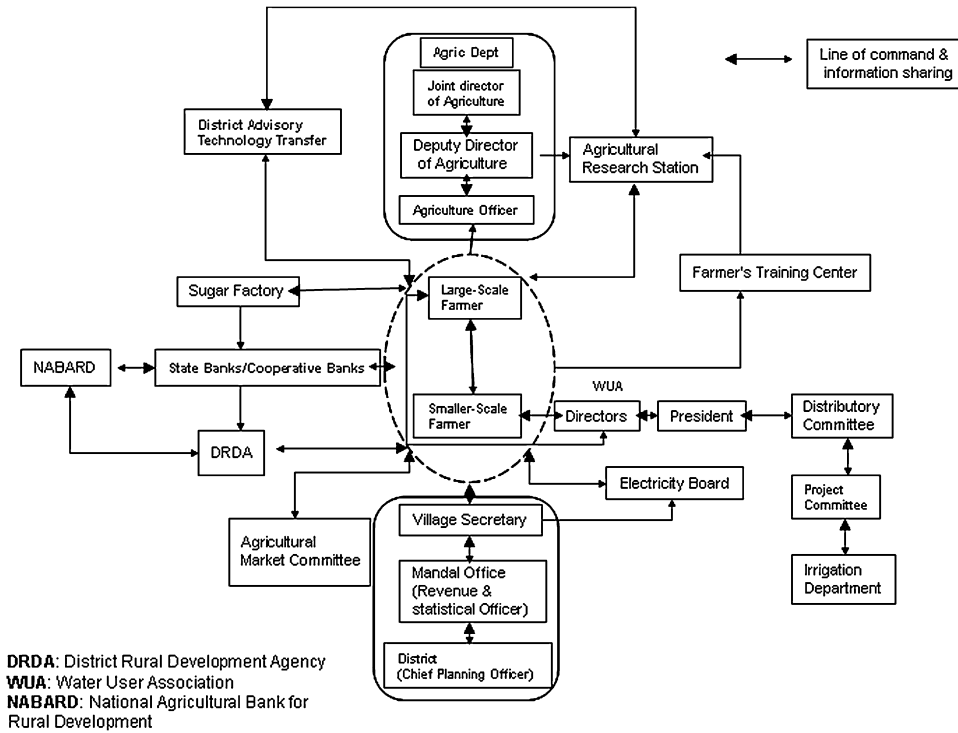


Fig. 3. Stakeholder setting in the study area.

stakeholders, their influence on the land use system, and their participation in the process of land use planning. Inferences of each of these stakeholders' role and their information-sharing, and communication were derived.

The SCM developed in this way is *not* an objective picture for the area, but is based on our perceptions and discussions with the stakeholders involved. As socio-economic-political conditions are dynamic in nature, the matrix undergoes

	Marginal / small scale farmer	Large farmer	Dist Agric Dept	District Rural Development Agency	Water Users Association	Agric Research Station / Scientists	Extension Service
Marginal / small scale farmer	-	●	•	•	•	•	•
Large scale farmer	●	-	●	●	●	●	•
Dist Agric Dept	•	●	-	•	•	●	●
District Rural Development Agency	•	●	•	-	•	•	•
Water Users Association	•	●	•	•	-	•	•
Agric Res Station / Scientists	•	●	●	•	•	-	●
Extension Service	•	•	●	•	•	●	-

- Relatively weaker interaction in information sharing / Communication
- Relatively stronger interaction in information sharing / Communication

Fig. 4. Stakeholder communication matrix.

modifications, sometimes on a real-time basis. Therefore, it has to be constantly updated if it is to be appropriately consulted.

4.1. The IMGLP model for Pitlam Mandal

A linear programming model is designed to optimise an objective function subject to a set of constraints; both the functions and constraints are formulated as linear equations (Chuvieco, 1993). An IMGLP model, that is designed to optimise (in successive iterations) a number of objective functions, has three components: (a) Objectives, (b) Constraints, (c) Activities or decision variables. Data on resources were available from the IMSD project, district statistical handbooks (CPO, 1995, 2001) and field data collection. In the present study, the model components a, b and c were specified on the basis of a participatory rural appraisal (PRA) and a stakeholder analysis. Scenarios were formulated on the basis of the major concerns of the various stakeholders as identified in the PRA.

4.1.1. Objectives

Based on societal, economic, environmental and policy concerns, eight objectives have been defined – (i) Economic: maximising farm income, minimising costs of production; (ii) Social: maximising food production; (iii) Environmental: minimising fertiliser use, minimising biocide use; (iv) Government/policy: minimising agricultural area, maximising employment, minimising water use. The objectives of the various stakeholder(s) groups are given in Table 2. The objectives have been defined based on interviews held with different stakeholders during the PRA exercise. The equations are given in Appendix A.

4.1.2. Constraints

The constraints relate to the resources available and include land, labour, capital and water: (i) land allocated to various activities cannot exceed total agricultural land available, (ii) labour allocated to the various activities cannot exceed the total available labour force, (iii) costs cannot exceed total available capital, and (iv) water use cannot exceed total available water. In addition, the objectives not being optimised in a particular optimisation (can) act as constraints. For example, limiting the area of paddy that can be sown in a particular

season or for other crops. The stakeholders, for example farmers, defined their constraints as “it is not possible to reduce land for paddy cultivation as it would adversely affect subsistence”, while the water user association would cite limited water availability to maintain current paddy area levels as the constraint.

4.1.3. Activities

The analysis focuses on crop selection; livestock hardly plays a role in the economy of the region, thus has not been considered in the current model. Twelve cropping activities have been identified as relevant in the current study: (i) Paddy Kharif (irrigated), (ii) Paddy Kharif (non-irrigated), (iii) Paddy Rabi (irrigated), (iv) Cotton Kharif (non-irrigated), (v) Sorghum Kharif (non-irrigated), (vi) Sorghum Rabi (non-irrigated), (vii) Green gram Kharif (non-irrigated), (viii) Green gram Rabi (non-irrigated), (ix) Black gram Kharif (non-irrigated), (x) Black gram Rabi (non-irrigated), (xi) Groundnut Kharif (non-irrigated), and (xii) Bajra Rabi (non-irrigated). Only current technology is considered, as the majority of the farmers are small- to medium-scale and significant technology-related modifications are not foreseen in the near future.

The technical coefficients have been derived from statistical records from the study area, field surveys, interviews with stakeholders and published literature (CPO, 1995, 2001). The model was formulated in General Algebraic Modelling System Integrated Development Environment (GAMS IDE) (GAMS, 1998).

The IMGLP model has been developed with a facility to incorporate additional functionalities if required and adaptations can easily be incorporated, if required by changing circumstances (new activities such as new crop types, new technologies, changes in parameters including costs and prices of products, population dynamics, labour force, changes in dietary preferences, changes in infrastructure).

4.1.4. Scenarios

In this study, we consider the interests of some of the most important stakeholders: farmers, policy makers and the water users association. In the study area, two important objectives of the farmers are increasing income and retaining paddy area. The objectives of the policy makers include increasing

Table 2
Stakeholder objectives

	Maximise food production	Maximise income	Maximise labour use	Minimise agricultural area	Minimise fertiliser use	Minimise biocide use	Minimise water use
Marginal/small-scale farmer	✓	–	–	–	–	–	–
Large-scale farmer	–	✓	–	–	–	–	–
District agricultural department	✓	–	–	✓	✓	✓	✓
District rural development agency	✓	✓	✓	✓	✓	✓	✓
Water users association	✓	–	–	–	–	–	✓
Agricultural research station/scientists	✓	–	–	✓	✓	✓	✓
Extension service	✓	–	–	–	✓	✓	✓

farmers' income, maintaining rural employment, improving water-use efficiency, reducing fertiliser and biocide use and discouraging farmers from cultivating marginal lands. The water users association's main objective is optimising water use. A number of scenarios can be constructed by different combinations of objectives and constraints. For illustrative purposes, we discuss three examples:

- (a) Maximise profit
- (b) Minimise water use
- (c) Maximise employment

In each of the scenarios, the following four options for achieving the desired outcomes are explored:

- (i) Maintain the current paddy area
- (ii) Reduction of 50% in the current paddy area
- (iii) Reduction of 20% in agriculture area, while maintaining the current paddy area
- (iv) Reduction of 20% in agricultural area and 50% in paddy area

Rice is the staple diet for the population of the region, who because of food security considerations, want to maintain the current paddy area. However, the policy of the District

administration aims at reducing the paddy area, because of water-related limitations. Therefore, reducing the current paddy area by 50% is explored as an option.

A reduction of 20% in agricultural land is explored to mimic abandonment of marginal lands currently under cultivation, comprising Kharif and Rabi non-irrigated lands. The Pitlam IMGLP model, containing Eqs. (1)–(11) from Appendix A and the technical coefficients, has been used to generate the objective values for the different scenarios (Table 3).

4.1.5. Interactive workshop with stakeholders

An interactive day-long research-feedback workshop was conducted in January 2004 in the state-of-the-art conference hall in the District Rural Development Agency's Office in Nizamabad District, where the IMGLP model was demonstrated and several scenarios were generated and the results discussed with the stakeholders. The District Administration led by the District Collector and the Project Director of the District Rural Development Agency supported the workshop with the necessary logistics. The 25 participants from different parts of the study area, some of which also participated during the fieldwork phases of the study, included small-scale and marginal farmers, large-scale farmers, officials of the water users association, field level agricultural extension officers,

Table 3
Objective values for different scenarios

Scenarios	<i>I</i> (Rs '000)	<i>L</i> (Man-days '000)	<i>F</i> ('000 kg)	<i>B</i> (kg)	<i>W</i> ('000 mm)	Paddy (ha)			So (ha)		SC (ha)	Co (ha)	GG (ha)		BG (ha)		<i>G</i> (ha)	% of total agric area
						Kirr	Knirr	Rirr	Knirr	Rnirr			Knirr	Rnirr	Knirr	Rnirr		
Base line	22 481	959	1110	4235	2908	1600	1000	1053	368	1225	630	529	980	87	980	88	654	91
S1	30 246	728	1139	7291	2908	2774	—	988	—	—	—	2576	1545	—	—	—	109	79
S2	20 917	948	1112	1391	2908	893	470	2399	2815	1545	1009	—	—	—	—	—	981	100
S3	15 606	831	1014	1368	2908	772	2990	—	—	—	1615	—	—	—	—	—	496	58
S4	29 376	728	1142	7271	2908	2628	—	1134	—	—	—	2579	1236	—	—	—	255	77
S5	21 093	921	1090	1386	2908	865	498	2399	2130	1236	1147	—	—	—	—	—	870	90
S6	16 522	831	1014	1368	2908	772	2629	361	—	—	1615	—	—	—	—	—	496	58
S7	33 211	593	965	8892	2139	1880	—	—	—	—	80	3286	1545	—	—	—	—	67
S8	24 701	863	914	1426	2220	1096	—	783	3286	1545	1787	—	—	—	—	—	—	84
S9	21 597	614	861	4784	1825	—	1806	73	—	—	—	1479	1545	—	—	—	2884	77
S10	31 686	620	933	7391	2144	1880	—	—	—	—	514	2629	1236	—	—	—	—	62
S11	24 877	836	892	1417	2209	1003	—	876	2629	1236	1880	—	—	—	—	—	—	75
S12	23 511	622	868	1498	1843	—	1048	831	—	—	—	1580	—	—	1236	—	2884	75

I, income; *L*, labour; *F*, fertiliser; *B*, biocide; *W*, water use; *So*, sorghum; *SC*, sugarcane; *Co*, cotton; *GG*, green gram (pulses); *BG*, black gram (pulses); *G*, groundnut; *Kirr*, Kharif irrigated; *Knirr*, Kharif non-irrigated; *Rirr*, Rabi irrigated; *Rnirr*, Rabi non-irrigated; *Rs*, Indian Rupees (1 US\$ ~45 Rs).

- S1: Maximise profit with current agricultural land and current paddy area.
 S2: Maximise employment with current agricultural land and current paddy area.
 S3: Minimise water use with current agricultural land and current paddy area.
 S4: Maximise profit with 20% reduction in current agricultural land and current paddy area.
 S5: Maximise employment with 20% reduction in agricultural land and current paddy area.
 S6: Minimise water use with 20% reduction in agricultural land and current paddy area.
 S7: Maximise profit with current agricultural land and 50% reduction in paddy area.
 S8: Maximise employment with current agricultural land and 50% reduction in paddy area.
 S9: Minimise water use with current agricultural land and 50% reduction in paddy area.
 S10: Maximise profit with 20% reduction in agricultural land and 50% reduction in paddy area.
 S11: Maximise employment with 20% reduction in agricultural land and 50% reduction in paddy area.
 S12: Minimise water use with 20% reduction in agricultural land and 50% reduction in paddy area.

district level agricultural officers and the project director of land and water management for the district.

5. Results of IMGLP

Scenario 1 (S1), maximising income while maintaining the current area of paddy (3763 ha), leads to a high level of biocide use (Table 3), as a consequence of 2576 ha being allocated to cotton (that under current crop management requires significant quantities of biocides). S2, where employment is maximised, leads to a 30% increase in labour use, a 44% reduction in income and a 424% reduction in biocide use, compared to S1. The reduced biocide use is the consequence of complete disappearance of cotton from the cropping pattern, while other commercial crops, such as sugarcane (1009 ha) and groundnut (981 ha) compensate for income generation. If the current paddy area and yields have to be maintained, reducing water use is not possible. Therefore, in this option (S3), in addition to the current paddy area, sugarcane (1615 ha) and groundnut (496 ha) are cultivated. When S3 is compared to S9, where water use is minimised, associated with a reduction of 50% in paddy area, a significant reduction (59%) in water use is achieved. Alternative crops in the latter case are cotton (1479 ha), green gram (1545 ha) and groundnut (2884 ha).

6. Combining the IMGLP model and the stakeholder communication matrix

The relevance of analysing the results of the scenarios generated with the IMGLP model in the context of an SCM can be illustrated with the sample set of scenarios. For example, consider Scenario 1 (in Table 3), which is preferred by the farmers, as income is maximum, while the paddy area is retained at the current level and there is no reduction in agricultural area. However, the Agricultural Department would identify more easily with Scenario 10, in which the paddy area is reduced by 50% and the agricultural area by 20%, in accordance with the policy of limiting the area of high water-demanding crops and dissuading farmers from cultivating marginal lands. Although maximum attainable income in S10 is about 5% higher than in S2, farmers prefer to maintain the current paddy area. This conflicting situation is compounded by the fact that communication between small-scale farmers and the Agricultural Department is relatively weak (Fig. 4). Another example is the conflict between Scenarios 1 and 12. In this case, farmers prefer S1, while the water users association's objective is minimising water use, i.e. encouraging cultivation of crops that are relatively less water-demanding and thus its preference is S12. Compared to S1, income in S12 is 22% lower, while water use is 36% lower, and there is a significant reduction in biocide use. Thus, analysing the scenarios generated with the IMGLP model in the context of the SCM leads to insight into the interactions among stakeholders in the system and to implementation of curative measures if required for improved communication.

7. Discussion

This study aimed at contributing to further development of tools for participatory land use analysis in support of land use policy formulation. Although (modest) successes have been reported in participatory regional planning (Hoefsloot and van den Berg, 1998), a recent analysis of such a process concludes: 'The biggest challenge in the methodology is probably its implementation in practice. One of the challenges is to select from a multitude of possible questions, those most relevant to the sustainable development of a region. That requires close cooperation with the various stakeholders. The relevant questions can only be addressed and translated into meaningful scenarios, if both the system and the scientists involved are sufficiently flexible/competent for demonstrating the scope for extension and limitations of the system. Another related challenge is, how to institutionalize this dialogue' (Roetter et al., 2005).

The study brought out the significance of developing an SCM as a means of understanding the social communication dynamics of the system. Hence, while the IMGLP model is a useful tool to model bio-economics of the land use system, the social context in which its results should be implemented determines their relevance. The SCM is thus a relevant tool to describe the interrelations among stakeholders with communication as an indicator and serves as a vehicle for stimulating cooperation between scientists and other stakeholders. Analysis of the IMGLP scenarios in the context of SCM provides insight into the possible bottlenecks obstructing negotiation and successful application of the model.

The workshop provided an opportunity to interact with the users on the basis of results of the IMGLP model, and to discern the usefulness and relevance of the study. The scenarios generated with the IMGLP model and the examples discussed in the context of the SCM served to demonstrate the model and to assess the usefulness of integrating both tools. It allowed observation of the reactions of district level planners to the information generated with the combined tools and its application in negotiation with the various stakeholders on the options and their consequences. There was enthusiastic participation and keen interest among the planners and the farmers to further explore the capabilities of the tool. It is intended to install the modelling tool in the district planning office where adequate facilities, including trained human resources, infrastructure such as computer labs and software are available. There are also disciplinary specialists, such as agronomists, soil scientists and hydrologists who can be involved in the application of the tool. Clearly, intensive training will be required to familiarize the potential users with the capabilities of the combined modelling system and the interpretation of the results, to avoid the effects of 'fools rushing in where angels fear to tread'.

Eventually, the farmers take the final decision on land use, based on their aspirations and objectives, within the prevailing socio-economic context and in response to the policy instruments that the administration utilizes in support of its initiatives. Such decisions are taken within the context of the farm household. Therefore, studies at the farm scale are required to investigate farm level possibilities in terms of

opportunities and constraints in response to different policy measures (Roetter et al., 2005).

8. Conclusions

An IMGLP model is useful as a negotiation support tool in agricultural policy formulation and the SCM matrix is a relevant addition to judge the position of various stakeholders in the negotiation process.

A more realistic representation of the farmers' decision-making process, however, would require inclusion of their attitude towards risk. A simple procedure, schematically describing one of the risk factors (i.e., of a delayed, inadequate or failed monsoon), could be incorporated in the analysis: in the IMGLP analysis, a scenario of, for instance, 0% or 10% paddy area (depending on the area that has already been planted before the situation of the monsoon is clear) could be generated for inclusion in the negotiations.

The SCM in the present study admittedly is a simplified representation of the complex relations between the various stakeholder groups. In addition to characterisation in terms of objectives, communication and/or information-sharing, the relations can also be described in terms of power characteristics, which have an impact on the negotiation process. In future developments that aspect needs more attention.

Acknowledgements

The authors acknowledge ITC for funding the PhD programme of Uday Bhaskar Nidumolu. Thanks are due to the District Rural Development Agency, District Planning Office in Nizamabad District for their cooperation in the course of this study, including participation and supporting fieldwork. Farmers of several villages in Pitlam Mandal are also acknowledged for their enthusiastic participation in the survey. So also Pitlam Mandal Office for facilitating the visits and interactions with farmers. The anonymous reviewers are thanked whose comments have helped to significantly improve the paper.

Appendix A

Mathematics of Pitlam Model

Constraints

$$\sum_{c,l} A_{c,l} \leq \text{TLan} \quad (1)$$

$$\sum_c L_{c,l} A_{c,l} \leq \text{TLab} \quad (2)$$

Profit constraint

$$\sum_{c,l} (P_c Y_{c,l} A_{c,l}) - \sum_{c,l} (Lc_c A_{c,l} + Fc_c A_{c,l} + Bc_c A_{c,l} + Oc_c A_{c,l}) > 0 \quad (3)$$

Cost constraint

$$\sum_{c,l} (Lc_c A_{c,l} + Fc_c A_{c,l} + Bc_c A_{c,l} + Oc_c A_{c,l}) \leq \text{TC} \quad (4)$$

Water constraint

$$\sum_{c,l} (W_c A_{c(l,t)}) \leq \text{TW} \quad (5)$$

Objective functions

Profit

$$\max P = \left\{ \sum_{c,l,t} (P_c Y_{c,l,t} A_{c,l,t}) - \sum_{c(l,t)} (Lc_c A_{c(l,t)}) - \sum_{c(l,t)} (Fc_c A_{c(l,t)}) - \sum_{c(l,t)} (Bc_c A_{c(l,t)}) - \sum_{c(l,t)} (Oc_c A_{c(l,t)}) \right\} \quad (6)$$

Labour

$$\max L = \sum_{c,l} (L_c A_{c,l}) \quad (7)$$

Water use

$$\min W = \sum_{c,l} (W_c A_{c,l}) \quad (8)$$

Costs

$$\min C = \sum_{c,l} (Lc_c A_{c,l} + Fc_c A_{c,l} + Bc_c A_{c,l} + Oc_c A_{c,l}) \quad (9)$$

Fertiliser

$$\min F = \sum_{c,l} (Fc_c A_{c,l}) \quad (10)$$

Biocide

$$\min B = \sum_{c,l} (Bc_c A_{c,l}) \quad (11)$$

List of indices, variables and coefficients

A = Area allocated to crop *c*

TLan = Total land available

l = Land type: irrigated or non-irrigated – Kirr, Knirr, Rirr, Rnirr (Kharif irrigated, Kharif non-irrigated, Rabi irrigated, Rabi non-irrigated)

c, l = crop per land type

L = Labour man-days required per crop per ha

TLab = Total labour available

P = price per crop
 Y = Yield per ha
 L_c = Labour costs per ha
 F_c = Fertiliser costs per ha
 B_c = Biocide costs per ha
 O_c = Other costs per ha
 TC = Total capital available
 W_c = Water required per crop per ha in mm
 TW = Total water available

Note: all costs and prices are in Indian rupees (1 US\$ ~ Rs 45).

References

- Bojórquez-Tapia, L.A., Diaz-Mondragón, S., Ezcurra, E., 2001. GIS-based approach for participatory decision making and land suitability assessment. *International Journal of Geoinformation Science* 15, 129–151.
- Chuvieco, E., 1993. Integration of linear programming and GIS for land use modelling. *International Journal of Geographical Information Systems* 7, 71–83.
- CPO (Chief Planning Officer), 1995, 2001. Handbook of Statistics – Nizamabad District, Nizamabad. CPO.
- De Wit, C.T., van Keulen, H., Seligman, N.G., Spharim, I., 1988. Application of interactive multiple goal techniques for analysis and planning of regional agricultural development. *Agricultural Systems* 26, 211–230.
- Dogliotti, S., 2003. Exploring options for sustainable development of vegetable farms in South Uruguay. PhD thesis, Wageningen University, Wageningen.
- FAO, 2002. Smallholder Farmers in India: Food Security and Agricultural Policy. Food and Agricultural Organisation, FAO Regional Office for Asia and the Pacific, Bangkok.
- GAMS, 1998. GAMS Development Corporation, 1217 Potomac Street, N.W., Washington.
- Ganzert, C., 1995. Konzeption für eine ökologische Agrarlandschaftsforschung. *Berichte der ANL, Beiheft 12 (Festschrift zum 70. Geburtstag von Prof. Dr. Wolfgang Haber)*, pp. 51–64.
- Grimble, R., Wellard, K., 1997. Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. *Agricultural Systems* 55, 173–193.
- Grimble, R., Chan, M.K., Aglionby, J., Quan, J., 1994. Trees and trade-offs: a stakeholder approach to natural resource management. Gatekeeper Series 52. Sustainable Agriculture Programme, International Institute for Environment and Development, London.
- Hagman, J., Murwira, K., 1994. Indigenous soil and water conservation in southern Zimbabwe: a study on techniques, historical changes and recent development under participatory research and extension. Project Research Report 13, Department of Agricultural and Extension Services (AGRITEX), Zimbabwe and GTZ.
- Hahn, A., 1998. Institutionalising participation on village level – the example of one community in south-west Burkina Faso. In: Scherler, C., Forster, R. (Eds.), *Beyond the Toolkit: Experiences with Institutionalising Participatory Approaches of GTZ-supported Projects in Rural Areas*. GTZ, Eschborn.
- Harmsen, K., Nidumolu, U.B., 2002. Land use planning for sustainable development in South Asia: an example from India. In: Navalgubd, R.R., Nayak, S.R., Sudarshana, R., Ravindran, S. (Eds.), *Resource and Environmental Monitoring*, vol. 34. ISPRS & SIS, pp. 1467–1475.
- Hengsdijk, H., van Ittersum, M.K., 2002. A goal-oriented approach to identify and engineer land use systems. *Agricultural Systems* 71, 231–247.
- Hoefsloot, A.M., van den Berg, L.M. (Eds.), 1998. Successful Examples of Participatory Regional Planning at the Meso-level. Towards Sustainable Land Use Through Negotiated Conflict Resolution. SC-DLO, Wageningen (Report 164).
- Huizing, H., Bronsveld, K., 1994. Interactive multiple-goal analysis for land use planning. *ITC Journal* 4, 366–373.
- Holling, C.S., Berkes, F., Folke, C., 1998. Science, sustainability and resource management. In: Berkes, F., Folke, C., Colding, J. (Eds.), *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge University Press, Cambridge, pp. 342–362.
- Kaur, R., Srivastava, R., Betne, R., Mishra, K., Dutta, D., 2004. Integration of linear programming and a watershed-scale hydrologic model for proposing an optimised land use plan and assessing its impact on soil conservation – a case study of the Nagwan watershed in the Hazaribagh district of Jharkand, India. *International Journal of Geographical Information Science* 18, 73–98.
- Lu, C.H., van Ittersum, M.K., Rabbinge, R., 2004. A scenario exploration of strategic land use options for the Loess Plateau in northern China. *Agricultural Systems* 79, 145–170.
- Lu, J., Zhaoqian, W., Penning de Vries, F.W.T., 2002. Application of interactive multiple goal programming for red soil watershed development: a case study of Qingshishan watershed. *Agricultural Systems* 73, 313–324.
- Mustajoki, J., Hämäläinen, R.P., Marttunen, M., 2004. Participatory multicriteria decision analysis with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling and Software* 19, 537–547.
- Najm, A.M., El-Fadel, M., 2005. Computer-based interface for an integrated soil and waste management optimisation model. *Environmental Modelling and Software* 19, 1151–1164.
- Nidumolu, U.B., de Bie, C.A.J.M., van Keulen, H., Skidmore, A.K., 2004. Enhancement of area-specific land use objectives for land development. *Land Degradation and Development* 15, 513–525.
- Nidumolu, U.B., Alanga, P., 2001. Natural Resources information generation for planning: an Indian example. *GIM International* 15, 77–79.
- NRSA (National Remote Sensing Agency), 1995. *IMSD Technical Guidelines*. NRSA, Hyderabad.
- Queensland Government, 1991. *Integrated Catchment Management: A Strategy for Achieving Sustainable and Balanced Use of Land, Water and Related Biological Resources*. Queensland Department of Primary Industries, Brisbane.
- Rabbinge, R., van Latesteijn, H.C., 1992. Long-term options for land use in the European Community. *Agricultural Systems* 40, 195–210.
- Ramirez, R., 1999. Stakeholder analysis and conflict management. In: Buckles, D. (Ed.), *Conflict and Collaboration in Natural Resource Management*. IDRC/World Bank Institute, Ottawa/Washington, DC.
- Reddy, P.L.S., Rao, K.P., 1999. Watershed development programmes in India: experiences, issues and future agenda. *Journal of Rural Development, India* 18 (3), 335–358.
- Roetter, R.P., Hoanh, C.T., Laborte, A.G., van Keulen, H., van Ittersum, M.K., Dreiser, C., van Diepen, C.A., de Ridder, N., van Laar, H.H., 2005. Integration of Systems Network (SysNet) tools for regional land use scenario analysis in Asia. *Environmental Modelling and Software* 20, 291–307.
- Röling, N., 1994. Platforms for decision making about eco-systems. In: Fresco, L.O., Stroosnijder, L., Bouma, J., van Keulen, H. (Eds.), *The Future of the Land. Mobilising and Integrating Knowledge for Land Use Options*. John Wiley, Chichester, pp. 386–393.
- Romero, C., Rehman, T., 1989. *Multiple Criteria Analysis for Agricultural Decisions*. Elsevier Science, Amsterdam.
- Sarkar, R.A., Quaddus, M.A., 2002. Modelling a nationwide crop planning problem using a multiple criteria decision making tool. *Computers & Industrial Engineering* 42, 541–553.
- Sarma, J.S., 1999. People's participation and community organisations in management of watersheds. *Journal of Rural Development, India* 18 (3), 421–438.
- Srivastava, O.N., 1999. Participatory planning and management of watershed projects – some considerations. *Journal of Rural Development, India* 18 (3), 381–394.
- Straif Bontkes, T., van Keulen, H., 2003. Modelling the dynamics of agricultural development at farm and regional level. *Agricultural Systems* 76, 379–396.
- Sujith Kumar, S., Vasisht, A.K., Hoanh, C.T., Aggarwal, P.K., Kalra, N., 2001. Linking socio-economics to the biophysical evaluation: the IMGLP model. In: Aggarwal, P.K., Roetter, R.P., Kalra, N., van Keulen, H., Hoanh, C.T., van Laar, H.H. (Eds.), *Land Use Analysis and Planning for Sustainable Food Security: With an Illustration for the State of Haryana, India*. Indian

- Agricultural Research Institute/International Rice Research Institute/Wageningen University and Research Centre, New Delhi/Los Baños/Wageningen.
- Tan, R.R., 2005. Application of symmetric fuzzy linear programming in life cycle assessment. *Environmental Modelling and Software* 20, 1343–1346.
- Tippett, J., 2005. The value of combining a systems view of sustainability with a participatory protocol for ecologically informed design in river basins. *Environmental Modelling and Software* 20, 119–139.
- Van Ittersum, M.K., Rabbinge, R., van Latesteijn, H.C., 1998. Exploratory land use studies and their role in strategic policy making. *Agricultural Systems* 58, 309–330.
- Van Ittersum, M.K., Roetter, R.P., van Keulen, H., de Ridder, N., Hoanh, C.T., Laborte, A.G., Aggarwal, P.K., Ismail, A.B., Tawang, A., 2004. A systems network (SysNet) approach for interactively evaluating strategic land use options at sub-national scale in South and South-east Asia. *Land Use Policy* 21, 101–113.
- Van Keulen, H., 1990. A multiple goal programming basis for analysing agricultural research and development. In: Rabbinge, R., Goudriaan, J., van Keulen, H., Penning de Vries, F.W.T., van Laar, H.H. (Eds.), *Theoretical Production Ecology: Reflections and Prospects*. Simulation Monograph 34. Pudoc, Wageningen, pp. 265–276.
- Van Keulen, H., Kuyvenhoven, A., Ruben, R., 1998. Sustainable land use and food security in developing countries: DLV's approach to policy support. *Agricultural Systems* 58, 285–307.
- Van Keulen, H., van Ittersum, M.K., Roetter, R.P., de Ridder, N., Hoanh, C.T., 2002. New approaches to support development of sustainable land use systems. In: *International Symposium on Sustaining Food Security and Managing Natural Resources in Southeast Asia – Challenges for the 21st Century*. Chiang Mai, January 8–11, 2002, CD-Rom.
- Van Kooten, G.C., 1993. *Land Resources Economics and Sustainable Development*. UBC Press, Vancouver.
- WSSD, 2002. World Summit for Sustainable Development, Johannesburg, South Africa, 26 August–4 September 2002. <http://www.johannesburgsummit.org/html/sustainable_dev/sustainable_dev.html> (accessed on 04.03.04.).
- Yugandhar, B.N., Jagarlapudi, V., Kochar, V., 1999. Watershed-based development in arid and semi-arid areas of Andhra Pradesh. *Journal of Rural Development, India* 18 (3), 471–504.
- Zander, P., Kächele, H., 1999. Modelling multiple objectives of land use for sustainable development. *Agricultural Systems* 59, 311–325.