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Conceptual model development for landscape management in the mountains of the Indian Himalayan region: an approach for sustainable socio-ecological development

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Abstract

This study aims at presenting a conceptual model for landscape management in the Himalayan region of India, using quantitative/mathematical approach. Keeping in view the requirement, (based on fifteen years empirical field work in the Himalayan region and as well as literature survey) the MODAM (Multiple Objectives Decision Support Tools for Landscape Management) model along with linear programming approach was adopted with a view to presenting additional methodological perspectives on interdisciplinary landscape research. The work has stemmed out from the original research contribution, which tries to integrate interdisciplinary research planning with landscape management related research in the Himalayan region. This biodiversity hotspot has relatively high complexity in terms of sustainable socioeconomic development vis a vis conservation and management of the resources. The concepts and insights presented in this article will provide the basis for a discussion, on decision-making issues among multidisciplinary experts with regard to sustainable socioecological development within complex environments.

Keywords:

Integrated interdisciplinary modeling, tradeoffs, sustainable development, Himalayas

Introduction

The Himalaya of India is one of the most important ecosystems of the world, harbouring a unique biodiversity and an important part of India's population. Unfortunately, the Himalayan landscape is being threatened by overexploitation on one hand; and on the other, the great Gangetic plains and its population and ecosystems are facing a grim situation due to increased runoff from the deforested landscape (Saxena et al. 2001). Hence, sustainable landscape management and development are crucial for several hundred million people in India (Ives and Messerli 1989; Singh 2002). More than 10% of the entire Himalayan region has been assigned for biodiversity conservation, natural resource management and development of the local economy and people (Nautiyal 2009). Sustainable landscape management is becoming a prime concern among researchers, policy planners and decision makers; it requires knowledge that goes beyond the boundary of any single discipline covering multiple objectives of researchers from different disciplines. The effectiveness of natural resource management requires a detailed understanding of the patterns and processes that exist within the natural system and the human institutions associated with the use of the resource (Deadman 1999). Therefore, to know the complexity of the system and its behavior under different socioeconomic conditions, a detailed understanding of the system is necessary (Nautiyal and Nayak 2010). This means that the character of the landscape is the result of the interface between man and nature. Therefore, it would be imperative to analyze the complexity of the human and ecosystem interaction and consequently propose a tool that would be helpful in understanding the science behind sustainable landscape management; such a tool could also provide feasible solutions through a problem-solving approach, to the problem of sustainable landscape management. However, in the Himalayan context, limited efforts have been made in terms of integrated modeling approaches (Rees et al. 2006). Therefore, it is important to present a theoretical modeling approach (Nautiyal 2008; Nautiyal and Kaechele 2009) for understanding the landscape functioning based on empirical studies; and it is also important to recognize that the conceptual model needs to be developed in view of its suitability to the complex Himalayan environment. The present study tries to develop/ present a conceptual model in order to make a transition from a qualitative/ descriptive approach to a quantitative/ mathematical one.

Study area and climate

The study area encompasses the central Indian Himalayan region, which is located between 30°17'N-30° 41'N latitude and 79°40'E-80°5'E longitude. The whole region is divided into three agroecological zones; the lower elevation (<1000m asl); the middle elevation (between 1000m and 1800m asl), and the higher elevation (>1800m asl). The current study focuses on the entire higher elevation zone of the Central Himalayas. The area is of great ecological importance due to its rich biodiversity and ecosystem services (Singh 2002). The world famous Valley of Flowers, National Park and the Nanda Devi Biosphere Reserve have been located in the region for ecosystem conservation and development of the local economy and its people. An overview of the area is given in Figure 1. There are about 10,000 people residing in 47 villages of which 10 have been studied in detail. The total population of the villages is 2,762 (947 male adults, 781 female adults, and 877 children below 15 years of age). The villages located in the higher elevational zone are similar and considered as a functional unit of development in the mountains of the Central Himalayan region (Nautiyal 2009). Therefore, considering the cluster of villages or a single village for long-term empirical study is equally important for designing new strategies for sustainable landscape development.

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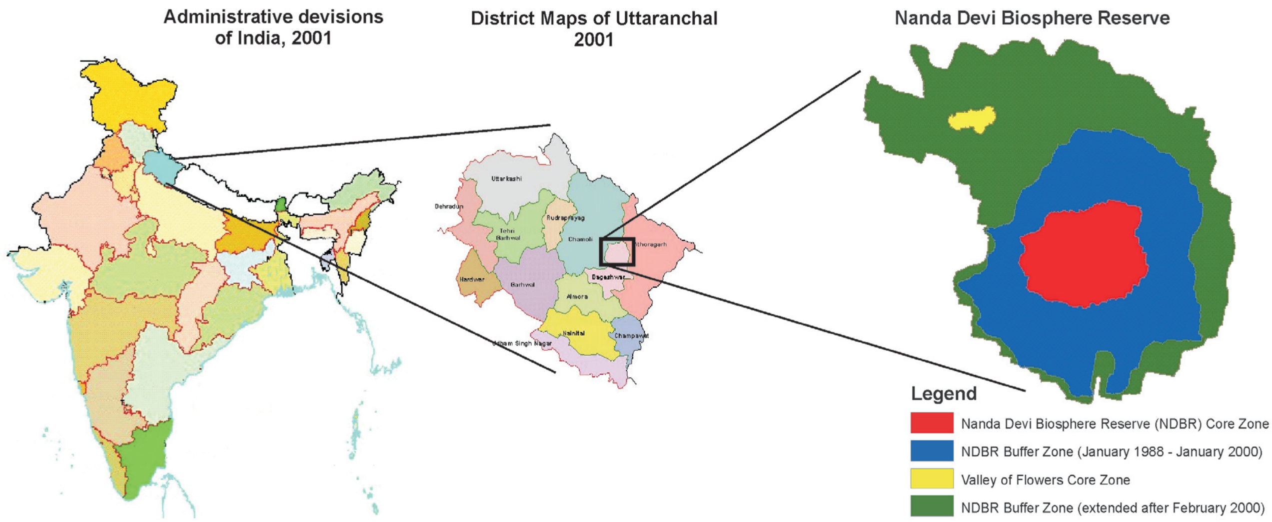

Figure 1: Location of the study area in the Indian Himalayan region.

Methodology

Design of methodological framework

Data obtained from empirical studies and remote sensing have been analyzed to explore the whole landscape in its multi-temporal and multidisciplinary dimensions (Nautiyal 1998, 2010; Maikhuri et al. 2000; Nautiyal et. al. 2001a, 2007; Rao et. al. 2005; Nautiyal and Kaechele 2007a,b). To determine the impact of scenario development (in view of the ex-ante simulation analysis) in the region, we have collected data sets for the last three to four decades from empirical studies and secondary sources such as the Census of India (2001). To understand the process of how the people change their activities in response to environmental, policy, socio-economic and other factors, and how the natural ecosystems respond to human activities, a long-term study of the region is essential. The work conducted during the past decade in the Himalayan region of India has facilitated the work in this direction, and accordingly we have developed the work-plan for data analysis (Figure 2). The whole framework is divided in five parts (A, B, C, D and E). Part 'A' comprises long-term empirical studies; part 'B' deals with the theory to understand the science of whole landscape management and development of the theoretical model; Part 'C' relates to the development of the conceptual model in the framework of current study and has now been completed; Part 'D' is ongoing with the development of software; Part 'E' is yet to be completed and plan to apply to our results to the real world situation. So far, in this research, researchers from multiple disciplines are invited for their suggestions in ongoing activities. The main aim is to use their suggestions for making necessary changes (if any) in the procedure. Such an approach is valuable for analyzing real world complexities (Bettinger and Boston 2001; Gemino and Wand 2004) as omitting the opinions of others in designing and developing the theory and concepts has been identified as a main reason for the lack of success in modeling efforts (Herrick et al. 2006; Gonzalez-Perez and Henderson Sellers 2007). Therefore, it is necessary that the theory and concepts are well defined and developed for real execution of the results in a real world scenario (Nautiyal 2008).

Analysis of existing data sets

The data analysis was carried out in detail for the whole region over three points of time; and this enabled to place the study from a microscopic viewpoint besides researchers' understanding of how farmers make their own decisions with regard to the landscape. The analysis also tried to understand inter-linkages and interdependencies, different production systems employed in the

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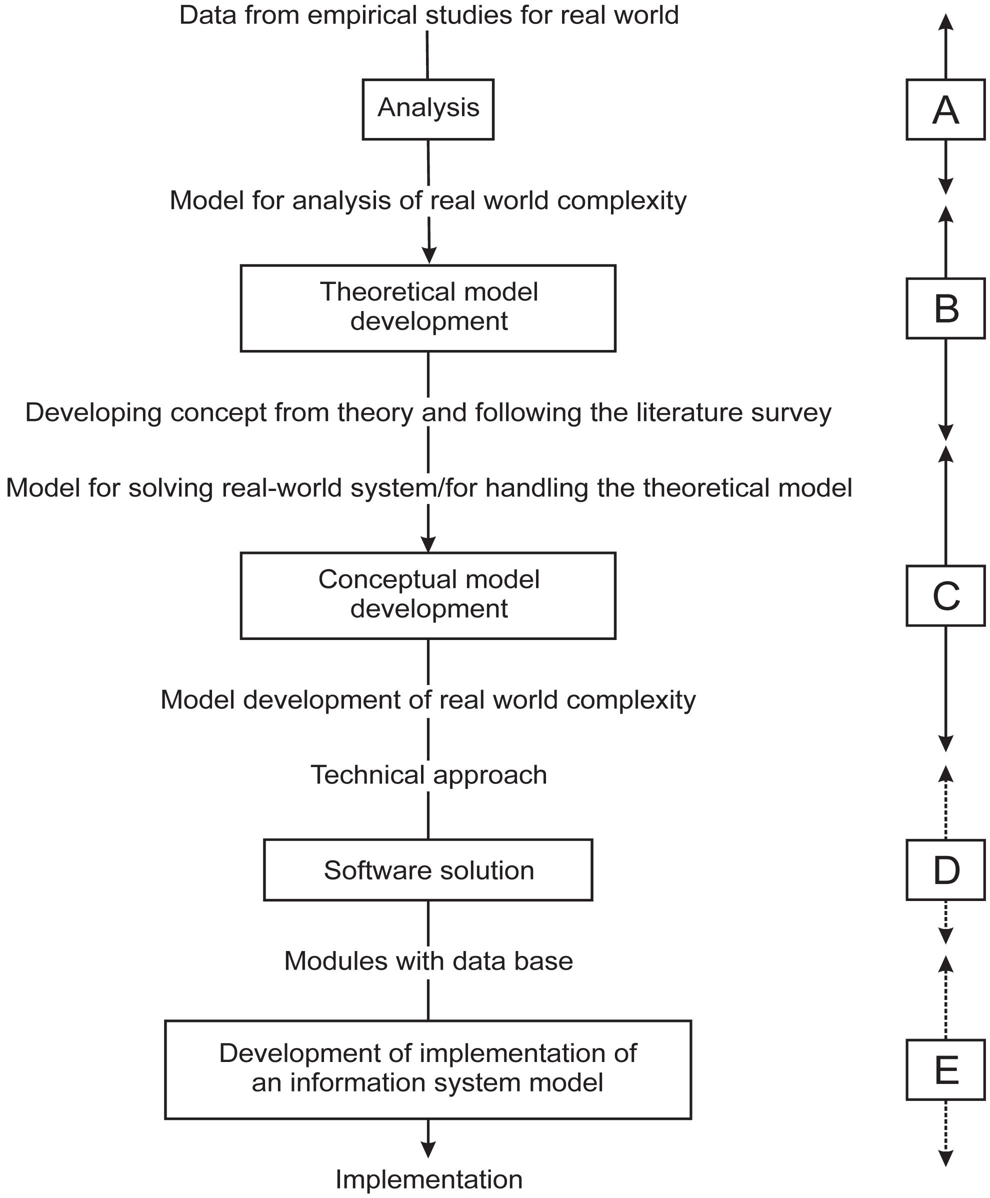

Figure 2. Research design for conceptual model development needed for the real world modeling.

landscape, such as agriculture, medicinal plants cultivation, forest resource collection, and animal husbandry using the ecological and economic currencies. The methodology pertaining to the study of agriculture, animal husbandry, forest and natural resource utilization patterns, and the whole village ecosystem function has been described in detail by Nautiyal (1998, 2008, 2010), Rao et al. (2005), Nautiyal and Kaechele (2007a,b), Nautiyal et al. (2007).

Development of the conceptual model

A detailed survey was conducted on literature, dealing with the development of a conceptual model for sustainable landscape management in the Himalayan landscape (Belovsky 1994; Dale et al. 1998; Bettinger 1999; Tulloch 1999; Martinez-Fernandez et al. 2000; Gomez-Sal et al. 2003; Moody 2005; Leleu 2006; Gonzalez-Perez and Henderson-Sellers 2007). Comparison was made in view of the requirement for handing the theoretical model and concurrently the appropriate methodology was synthesized to develop the concepts for the outcome of the conceptual model.

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Results

Outcome of empirical studies

The empirical studies have covered every branch of the ecosystems (such as agriculture, forests, animal husbandry, etc.) of the Himalayan region; and an analysis was done using the identified ecological and economic indicators. The review of empirical studies was undertaken with a view to understanding the human and ecosystem interactions in the context of changing environmental, political and economic conditions.

Innovation and peoples' behavior

We have studied that why and how people change their way of earnings (including land use) under changing environments (natural and technological) and socioeconomic conditions. The demographic examination at the very beginning of the study has been helpful into designing the road map for further activities. The working population in the agriculture sector and the land use pattern have drastically changed in the last three decades. We have noticed that farmers have been trying to explore different sources of income to sustain their lifestyles in these fragile environmental conditions. For the current analysis, we have considered 1970–80 (t1) as the starting period for studying farmers' behavior and ecosystem functioning of the region. Since 't1' we have analysed the system's functioning and subsequently the behavior of the farmers of the area. Meanwhile, the activities are emphasized where a local economy is centered.

Due to strict conservation policies, such as land segregation for national parks and biosphere reserves, tourism sector has suffered a setback in the region. However, it was observed that while the involvement in animal husbandry has declined, the interest in other occupations, such as labor and service, is increasing.

Land use in study region

In the region, rain fed agriculture on steep terraces is the predominant form of land use. At present, the average per capita land holding ranges from 0.15–0.21 ha, however, the average decadal growth rate for the study region for the last two to three decades has been 15.74% (Census of India 2001). Therefore, the per capita land holding decreased by 0.023ha - 0.033ha during decadal intervals. From the period 1970–80 to 1980–90, the land use under many traditional crops such as *Fagopyrum* spp. (buckwheat), *Eleusine coracana* (finger millet), *Panicum miliaceum* (hog millet), *Triticum aestivum* (wheat), *Hordeum vulgare* (jau) and *H. himalayens* (naked barley) reduced from 15% to 60%. This trend continued, and in the year 2000, land use under traditional crops decreased between 50% and 96% (Nautiyal 1998). However, the average annual agricultural land productivity per ha increased from 286kg in 1970–80 to 394kg in 1980–90 to 579 kg in 1990–2000 (Nautiyal 2010).

The spatial distribution of farmer activities and related land uses in the region has been documented for decades. During the period 1970–80, the bulk of farm income came from animal husbandry, followed by tourism-related activities. Very few farmers were involved in commercial agricultural activities. With the implementation of conservation policies and the diminution of traditional usufruct rights of local people over the natural resources, the tourism/mountaineering activities are completely banned in the core zone of the biosphere reserve, which has negatively affected the local economy of the region. Consequently, farmers have turned towards commercial agricultural operations. From 2000 onwards, significant income has been coming from agriculture with high land use intensification. The domestication of wild medicinal and aromatic plants has turned out to be a new paradigm shift in the Himalayan region. The people have adopted this activity as a problem-solving component in their economics (Nautiyal 1998; Maikhuri et al. 1998). In 1970, this sector accounted only for about 0.2% of the total household income, but now accounts for about 2-3 percent. However, the agricultural sector contributes more than 60% of the total gross income, though it accounted only for 14% of total income of farmers three decades ago (Nautiyal 2010).

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The forest ecosystem and resource collection

The change in production systems as well as increase in productivity bring about a change in the input especially from the forest ecosystems. The production and consumption activities (input/output) resulting from different branches in landscape management, are interlinked to each other, and hence they influence the whole functioning of the ecosystems. Traditional agriculture is dependent on the surrounding forest resources. The perseverance of the farmer to secure the optimum output from agriculture is reflected in the per capita per year collection of leaf litter increasing to 222 kg/year (t3) from 100 kg/year (t1). To maximize the production from each unit of land, the dependency for input flow in terms of resource collection from the forests has increased tremendously (Semwal et al. 2004). There are several other reasons, such as the fodder (crop by product) yield decreasing by up to 35–70% and replacement of traditional varieties with the introduction of high yielding varieties are some of the factors found responsible for the high exploitation of forest resources (Nautiyal et al. 2007).

Other resource demands, such as non-timber forest product collection (NTFPs) from the forests and alpine pastures, have been quantified making a significant contribution to the local economy. We have noticed that three decades ago (1970–1980) the NTFPs collection in the form of medicinal and aromatic plants and other wild edibles accounted for 10% of the total gross income of the farmers, which increased to 16% during the period of 1980–1990. Continuing the trend, this sector contributed 18% of the total household income during 1990-2000.

Theoretical model development

The theoretical model (Figure 3) was developed based on the following components of the whole integrated process: drivers, farmers' options, rules of farmers' decision making, simulate farmers' decision with respect to drivers, indicators to measure the farmers' decisions, and the overall trend of landscape development. Approach to the theoretical model developed for the Himalayan landscape contains six modules/components (T1 - T6).

Drivers (T^1)

These standard driving forces influence farmers' decisions and include environmental and socio-economic resources, policies, and the national economy. Such drivers are widely accepted from a global to a local scale (Lonergan et al. 2000; IPCC 2001).

Farmers' decisions (T^2)

Farmers' decisions determine their economic success as well as the ecological performance of the chosen management systems. The achievement of economic goals is generally a priority for farmers and this is one of the outcomes of the theoretical model. In reality, the ecosystem analysis leads to evaluation of the efficiency of the system in terms of economic goals. The decision-making behavior of farmers is centered around the criterion of maximizing income from the available resources to farmers. Thus, investigations have been carried out to evaluate the attitudes of farmers towards overall scenario changes and development, and also how farmers assess different conditions, such as the implementation of policies, socio-economic changes, population growth, national economy, limitations of land use, resource availability, and infrastructure. Finally, it was observed that farmers seem to focus on three to four potential options for maximizing their incomes.

Farmers' options to sustain their livelihoods (T^3)

Since farmers' options for sustaining their livelihoods vary from region to region, it is necessary to consider all the associated practices/backgrounds that directly or indirectly influence those options. Options include both the traditional/current practices, as well as new possibilities identified by scientists. This review identified the maximization of income as the primary motivation for farmers. Presumably, farmers have to choose those options having the greatest likelihood of securing their livelihoods.

Indicators to measure farmer's decisions (T^4, T^5)

Human-ecosystem interaction influences the process of landscape development (Nautiyal 2008; Nautiyal and Kaechele 2009). Hence, all possible decisions by farmers should be evaluated from a socioeconomic and ecological viewpoint that reflects a range of pos-

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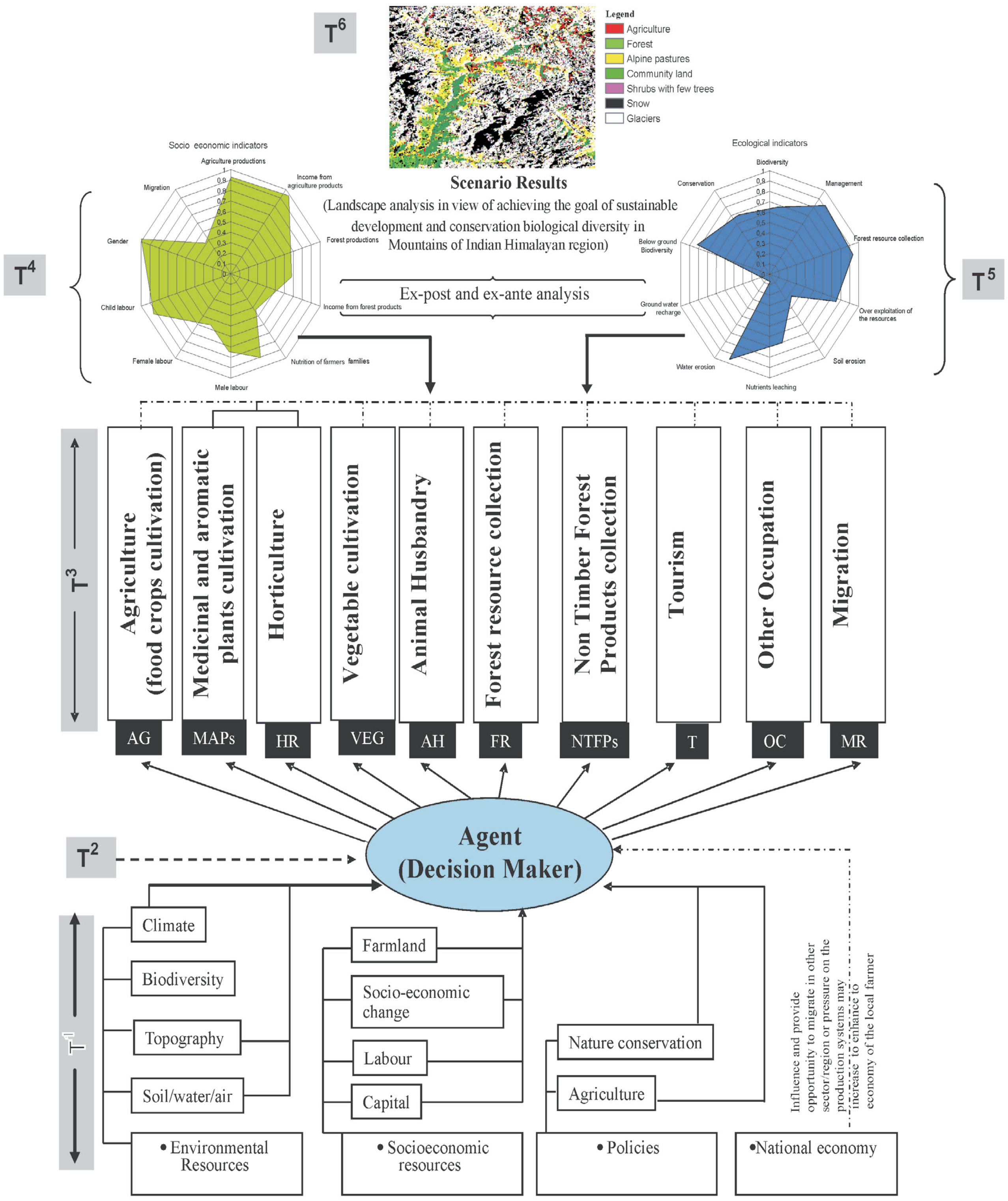

Figure. 3. Development of theoretical model is beginning for development of whole model system MODAM for Himalayan region. (T1, T2, T3, T4, T5 and T6 : modules of theoretical model development) (Nautiyal and Kaechele 2009).

sible indicators. Such indicators would then be used by farmers to choose the most feasible options. This approach enables the landscape development and examines the magnitude of the use of the resources, such as land, and changes in the use of resource dynamics over time (for example, use of forest resources to sustain the traditional land use). The decisions by the farmers in the region are determined by expected economic returns, altered by attitudes towards risk. At present, empirical evidence shows that the agriculture sector is very remunerative for farmers, and therefore, they tend to focus their attention on agriculture-related activities. To understand this phenomenon in our study region, we have considered the tradeoffs between economic (T4) and ecological (T5) criteria implied by selecting different landscape scenarios. At present, relinquishment of the benefit/advantage from land use has considerable ecological consequences. Thus, the hypotheses are framed in terms of relationships between socioeconomic indicators, such as income, labor, land, stable and capital, and ecological indicators, such as soil erosion, biodiversity, nutrient cycling, pollution, and soil fertility. In order to analyze such tradeoffs, multiple indicators need to be considered simultaneously; this is the key requirement to understand the science behind the analysis of landscape (Tittonell et al. 2007).

Overall trend of landscape development (T^6)

Drivers, constraints, and the economic and ecological performances (of management systems) influence farmers' selection of a management system. A change in driving forces can result in different (new) decisions by farmers, and therefore, new economic and ecological performances emerge. There are several ways to evaluate the overall trend of scenario development based on the empirical evidences and primary, secondary data collection. Here an attempt was made to develop a conceptual model that would capture the complexity of decision making in mountain landscapes and evaluate changes in resource use over space and time.

Discussion

From theory to a conceptual research approach

Rapidel et al. (2006) states that in a systematic approach, theory and concepts are used to represent the system, designed to address specific questions. The theoretical approach described in the previous section is considered a reasonable representative of the complex Himalayan landscape system, useful for understanding the past landscape management as well as predicting future scenarios of landscape development. For such a development model, it is important to first develop the 'concept' which supports the theory that underlying the long term empirical studies. However, the same approach could be used to evaluate the non economic performance of the system, such as the soil erosion, resource collection from the forests to sustain the farming system, and the overall ecological soundness of the system (Nautiyal and Nayak 2010). Thus, the theoretical approach attempts to extend the research objectives to include both the economic and ecological evaluation of the ecosystems/landscape. The model needs to meet all the above modules of the theoretical approach in an integrated and interdisciplinary way.

The conceptual modeling approach should be based on a strong theoretical underpinning, because using ill-defined concepts can lead to potential misinterpretations and even a failure of the model. To develop a model, it is first necessary to understand the theory or the subject of the study, is part of reality or real world, then, a model of it can also be part of reality (Gonzalez-Perez and Henderson-Sellers 2007).

General requirements of a conceptual model

The requirements of a conceptual model have been presented in the following two subsections.

Stemming from empirical research topic

In a systematic conceptual approach, the model is defined

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by its limit (1), components (2), environment (3), and the most relevant state variables (4) and flow of resources (5) and information within the system (Walliser 1997 cited in Rapidel et al. 2006 under concept of model section), as well as dynamic aspects such as exchanges with the environment (Lee et al. 2003). In our model, the system approaches for the landscape management are described as follows:

1. The limit of our current approach is that it could only fit in the areas dominated by forest-based agricultural land use systems.
2. The component (T1–T6) in system approach has been already explained in detail.
3. The environment deals with broad ecological and economic perspectives.
4. In the case of our current approach, the state variables include land, labor, topography, national economy, population growth; in the case of T3 (as above), the possible activities in landscape management, the branches are also state variables. In the case of specification of the socioeconomic indicators (T4) ecological indicators (T5) are also state variables.

5a. Flow of resources in our system approach is the process that contains behaviors which describe what farmers in the landscape do with the resources provided through state variables and characteristics and consequently, how the whole processes have an effect on the flow of resources. For example, the nature conservation policies influence farmers' decisions which in turn, affect the whole process in the context of resource flow, and this has an impact on the socioeconomics and ecological scenario of the entire landscape.

In a more general formulation, this scenario can be described as follows (Hazell and Norton, 1986):

This could be explained as $Z = f(b)$ in case of resources (state variables). But, if resources are increased by a factor of proportionality k, specifically,

$$f(kb) = kf(b) = kZ$$

Since

$$Z = \sum_i c_i X_i$$

Z is objective function and b is fixed resources of state variables

and the c_i coefficients are constants, it follows that

$$kZ = \sum_i c_i (kX_i)$$

It means if resource flows are increasing, then all activity levels increase and the objective function value also increases (such as productivity of a unit of farm land influenced by different resource input flow).

5b. Flow variables as well may refer on the dynamic view of a system approach. This refers to the overall understanding of the whole scenario results in time, as well as the causes and consequences of the changes in scenario results due to flow variables. The meaning of flow variables describes the development of state variables or describes the dynamic aspect of state variables in time, for example, change in policy, technical progress or climate change. This approach ranges from small to detailed representations of landscape processes.

Stemming from additional methodological perspectives

In addition to the above requirements, further needs are claimed by other researchers such as Gonzalez-Perez and Henderson-Sellers (2007) Moody (2005) and these are further illustrated from a viewpoint of real world analysis (6), indicators (7), adoption practices, improvement possibilities in the future respectively (8), for the purpose of evaluating the developmental process in the landscape. There should be emphasis on risk assessment as most of the researchers argue for handling this aspect in overall model development (Kaechele and Dabbert 2002).

6. Real world analysis: This is because the models need to have empirical evidence, hence empirical studies are important to justify and evaluate the outcomes of model; lacking this approach has been identified as the most common cause of failure in implementing models for real world analysis.
7. Indicators: In monitoring the state of rural landscape, every variable cannot be measured, therefore, well-chosen indicators help summarize the complex information (Farrow and Winograd 2001).

8. The successful generalization of the conceptual model depends on how crucial issues - such as adoption practices, possibilities for further improvement whenever needed, and knowledge about the projection and practices - have been addressed in the development procedure (Moody 2005).

State of art of modeling approach

The above derived requirements were used to assess or evaluate the present bio-economic landscape modeling approaches. Our review suggests that methods and theory testing approaches stemming from our own research are primarily geared towards construction of further conceptual models through the rationale of converging findings in line with empirical studies concurrently with the process of development of our theoretical model. There are several other methods focusing on conceptual model development and the implementation of sustainable natural resource management (Martinez-Fernandez et al. 2000; Petalas et al. 2005); however, the emphasis was given on some specific methodologies where the approaches were found identical to current research concepts as in the case of the Himalayas of India. To accomplish this, a literature survey was conducted with a view to solving the problems of real world complexities in the form of conceptual model development (Van Riet and Cooks 1990; Tulloch 1999; Bettinger 1999; Jackson et al. 2000; Bettinger and Boston 2001; Kaechele and Dabbert 2002; Gomez-Sal et al. 2003; Zander, 2003; Hillman et al. 2005; Janssen and van Ittersum 2007). A comparison of few a models was undertaken to assist the development of methodological perspectives. It was articulated that every model has its own advantages and limitations (Table 1). For example, Tulloch's (1999) model has the ultimate approach to database development, record-keeping for future perspectives, but is inadequate for ex-ante analysis besides having limited efficiency in handling real world complexities. Bettinger (1999) and Bettinger and Boston (2001) describe four systems - society, database development, technology - and the organizational commitment to implement these in a competent way, but this would be ideal for a simple situation to evaluate the outcome of projects but lacks the ability to handle the complex natural environment. Likewise, with regard to several other issues, every model has its own advantages and shortcomings.

The methods were evaluated for model development taking into consideration the current research requirements in terms of potential (model description) and shortcomings (where methods do not cover the specific obligation in view of our theoretical approach). These are shown in Table 1.

Baseline for conceptual model development

Based on the literature survey, it was noticed that at present, there is no such model that fits in a way that we can copy 1:1 in view of the complexity of the current research area. We found that the methodological approaches provided by Kaechele and Dabbert (2002), Zander (2003) for developing the model system MODAM (Multiple Objectives Decision Support Tools for Agroecosystem Management) fit in best in terms of solving the complexities. Although this approach has shortcomings but they can be standardized in the process of model development. The main issues which the model system (MODAM) emphasizes are field knowledge, empirical evidences and real world analysis, and underpinning of theory and concept in an integrated interdisciplinary approach; hence it is suitable for ex-post analysis and significant for ex-ante planning problems. The outcomes need to be presented in such a way that they address the needs of stakeholders in an indefinite future. Thus the strategy must satisfy social, economic, and ecological needs and the fact that these outcomes should continue into the future imply the need to support sustainable landscape management (Hillman et al.2005). For handling the complexity of the mountain environment, it is necessary to demonstrate the framework in view of its multi-objectives system function. Long research experience suggests that a single objective goal would be inadequate to address the problem and prospects of the whole landscape in the Himalayas. Concurrently, the bases for integrated interdisciplinary research have been designed in MODAM framework. The major shortcomings of model system MODAM are: (i) it cannot control the risk/uncertainty, (ii) it may face the problems in the case of additional external variables; and (iii) it does not have much efficiency in the dynamic aspects of the model. Inspite of these few shortcomings, the model system MODAM offers an opportunity to provide feasible solutions for sustainable landscape management. The problem related to risk/uncertainty could be handled

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Table 1. Comparison between process models from the literature and proposed conceptual model system MODAM development in this research

Models	Method	Model description	Shortcomings*
Tulloch (1999)	Theory development (Hypothetical)	Model developed for multiple uses of land use systems and emerged with the considerable comparison among the exitsing models for landscape management	1. Handling the complexities of real world such as interaction among the sectors etc 2. Policy scenario analysis 3. Integrated interdisciplinary research 4. Ex-ante analysis 5. Potential for the changes as per change in real world scenario 6. Risk/uncertainty
Van Riet and Cooks (1990)	Dynamic	Ecological planning of natural resource management and landscape development in view of the inter-action between human and nature	1. Policies development analysis 2. Scope for integrared interdisciplinary approach 3. Conceptual development 4. Scenario development analysis 5. Risk/uncertainty
Bettinger and Boston (2001)	Dynamic/ Conceptual	Focused on four conponents of the model such as people databases; technology nad organitational commitment to be executed	1. Integrated interdisciplinary approach 2. Potential for the changes as per change in real world scenario 3. Risk/uncertainty
Gomez-Sal et al. (2003)	Multivariate analysis	Assessment of landscape in view points of multi-dimension such as social, cultural, economic, ecological and production system analysis	1. Policy implementation analysis 2. Scenario development (ex-ante simulation) 3. Potential for the changes as per change in real world scenario 4. Risk/uncertainty
Hillman et al. (2005)	Theoretical/ hypothetical	Multidisciplinary apporaches for natoral resouces management	1. Policies scenario analysis, 2. Concepts framework and tool to solve the complexity 3. Risk/uncertainty
Janssen and van Ittersum (2007)	Mechanistic	Bio-economic farm models Easy understandable Simple and less demanding	1. Potential for the changes as per change in reak world scenario 2. Multidimensional 3. Interdisciplinary research 4. Risk/uncertainty
Model System MODAM Kaechele & Dabbert (2002), Zander (2003)	Linear Programming	Integrated interdisciplinary landscape research; Tradeoffs/ Planning, ex-ante analysis and scenario analysis and potential for the modification	1. Risk/uncertainty 2. Dynamic aspect 3. Additional external variables

* (Note) Shortcomings are described from the viewpoint of our requirements, not in general. For example, many models are interdisciplinary but we use the term integrated interdisciplinary and this is one of our requirements to handle the complexity of our theoretical model (for detail please see Fig. 3).

during the process of development as in current conceptual model, flexibility is one of the components which offers us further development in the model system. For example, changes in land use activities and resource input are proportionate to production-related parameters of farm management. The model should always offer a chance for improvement in the different modules of the whole model, according to the changes in the real world scenario.

An overview of conceptual model development
The whole MODAM consists of several databases and Linear Programming (LP) modules (Kaechele and Dabbert 2002; Zander 2003). As our aim is mainly to follow the MODAM approach, hence concentration was on the conceptual core of MODAM - the LP modules. Database development to LP is interesting from a software point of view. Choosing LP seems to be adequate, and hence, comments of some authors are referred here concerning this approach. Before going into details, we would like to provide a basic overview of Linear Programming in landscape modeling.

For multidisciplinary problems of the real world, we argue for bio-economic models which are helpful in solving the problems of economics and ecological complexities simultaneously. In the real world, when models are used to evaluate possible changes in land use under different sets of technological and socio-economic and ecological conditions, they are known as mechanistic bio-economic farm models (Ruben et al. 1998, cited in Janssen and van Ittersum 2007). Often, when such mechanistic models are applied, Linear Programming (LP) or some derivatives of LP are also used (Balasubramamiam et al. 1996; Janssen and van Ittersum 2007). The LP model for farm analysis is explained in detail by Ten Berge et al. (2000); and the use of LP is very sophisticated in modeling without high additional costs in terms of programming development, and therefore, could be used smoothly in producing the results from the models (Leleu 2006).

Linear Programming models are big equation systems. In mathematics, LP problems are optimization problems in which the objective function and the constraints are linear - so as to integrate capacity of farms and possible activities of farm management. In this equation system, the capacities are positioned on left-hand side of the equation and the demand of the activities (expressed in so called technical coefficients) concerning each capacity is placed on the right-hand side of the equation system. This is expressed as follows:

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} \begin{matrix} \geq \\ = \\ \leq \end{matrix} \begin{pmatrix} a_1 b_1 \ldots\ldots\ldots z_1 \\ a_2 b_2 \ldots\ldots\ldots z_2 \\ a_3 b_3 \ldots\ldots\ldots z_3 \end{pmatrix} \times \begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix}$$

The y vector defines capacity, a,b . . . z technical coefficients in the matrix and the target function- x vector describes the activities part in the matrix

The description is made by Ten Berge et al. (2000) for each farm activity (called operation or production practices) with corresponding inputs and outputs. To obtain certain output levels, different activities need to be defined so as to model for the different input levels, for example, the availability of labor, and available quantity of the resources (which vary from region to region and in the case of mountain farming, we can say, the quantity of farmyard manure, collection of the resources from the forests, capital and stables etc). For farm activities, the inputs such as labor and manure are limited resources and the constraints with regard to these resources need to be taken into consideration to understand as to how the minimum or maximum amount of that particular input can be used for this production system. The activities and constraints are then optimized in view of a specific objective function, for example, in production systems, we can use the productivity or net profit from the field (Janssen and van Ittersum 2007). The standard mathematical notation for the LP model can be represented by Max≥0.

*e.g., to maximize the gross margin

$$MaxZ = \sum_{i=1}^{n} c_i \bar{x_i}$$

Subject to ax ≤b; x≥0

Where Z is the objective function: a linear function of the n production activities (x) and their respective con-

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tributions (c–coefficients) to the objective. ax<b representing m linear constraints with right-hand side b. a is an m x n matrix with total coefficients (Hazell and Norton 1986).

LP may foster diversity by providing a variety of approaches such as behavioral (farmers' decisions to behave on the landscape) and environmental information (overall scenario development, interaction and interdependencies of all the branches of the ecosystems) and consequently has the ability to bring together a variety of datasets to be incorporated in a problem-solving scenario Belovsky (1994). Huggard (1994) and others express underlying philosophical concern regarding LP and that the predictive success of a simple LP model is questionable in view of the complexities of the real world (cited in Belovsky 1994 under conclusion section). Hobbs (1990), Belovsky (1990) point out that LP could be misleading or even wrong, if it is built upon erroneous assumptions. But the successes of LP would not indicate such illogical hypotheses. To question LP's successes, one must argue for an inherent flaw in its structure or in data collected to test it (Belovsky 1994 under conclusion section). Therefore, the empirically tested models argue for LP. It is not as complex as other modeling approaches and does not need more labor, allows researchers to deal with more sophisticated models without high additional cost in terms of program development efforts and specific expertise needed for other complex programming in models. The duality in LP is also a major benefit as duality offers a way to include economic and ecological goal functions in the evaluation process. Finally, LP software solves the models without having to introduce/apply a specific enumeration algorithm for each new module (Leleu 2006).

Superimposition of theory and concept needed for real world modeling in MODAM:
Drawing upon the theoretical approach, the following paragraphs deal with implementation of multidisciplinary land management in the modeling system, MODAM. Our theoretical approach (T1-T6) and conceptual model developments 'C1-C6' (Figure 4) are linked to each other, and hence, the conceptual model would have the potential to handle the theoretical problems of the real world. The theory and concept described here could perhaps become a basis for discussion among the researchers of an interdisciplinary team.

Restrictions (T^1 C^1):
These are constraints and represent the drivers, visualizing their presence in the landscape scenario and the farmer has to act accordingly opting for the feasible alternatives where these restrictions pose minimal hurdles. These are expressed as external variables such as environmental resources (land availability, climatic conditions), socioeconomic resources (labor and capital), policies (subsidies, nature conservation strategies) and national economy (competition for labor and capital). The quantification of variables delivers the left-hand side of the LP equation system. In a LP modeling system, the ecological restrictions are derived from the environmental resources while socioeconomic, political and national economy factors become the economic restrictions.

Goal function (T^2 C^2):
Goal function simulates the decision-making of farmers in terms of maximizing their income. Therefore, the model chooses several activities that best utilize the given resources which are restricted by external factors such as environmental or political. This procedure leads to maximization of income level.

Activities in landscape management (T^3 C^3):
In landscape management there are a lot of options available regarding farmers' ease of access to each branch. For example, in agriculture it is possible for farmers to cultivate several varieties of wheat, paddy, finger millet under different management practices. In animal husbandry farmers have options to choose any kind of livestock husbandry, further, they can select different races for different management practices. In the parlance of LP modeling, options are termed activities. Hence, current approach is to provide as many activities as possible for the farmers covering all the branches. They might choose a few of them with a view to sustaining their livelihood (see C^2).

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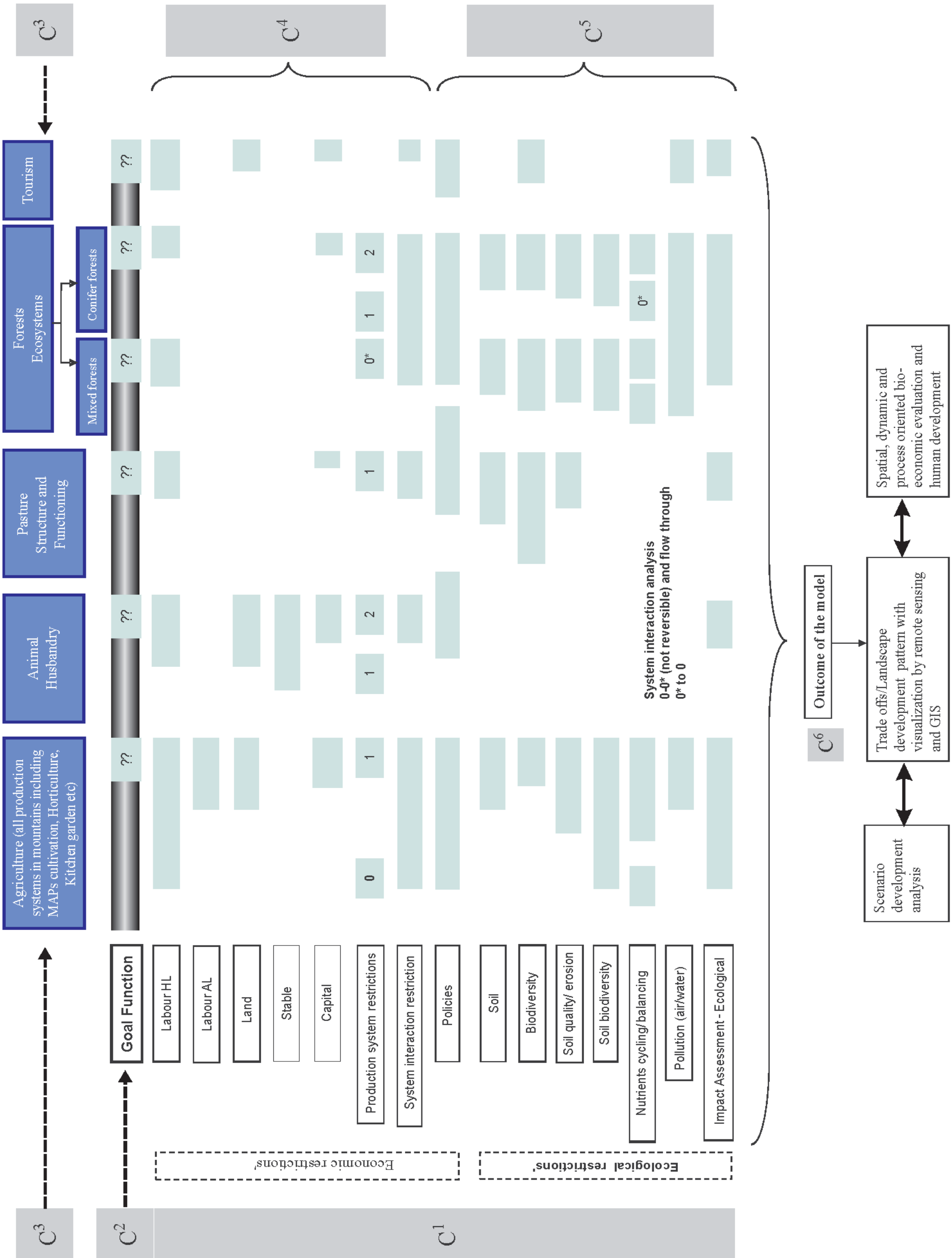

Figure 4. The Conceptual model system MODAM for mountains of the Indian Himalayan region (C1, C2, ... C6 : modules of conceptual model development).

Technical coefficient in view of economic restriction (T^4 C^4):

Each activity has to be evaluated in view of socioeconomic indicators such as demand for labor, capital, farm land, education, healthcare system and the benefit each activity provides for income generation of farmers. The outcome of this evaluation in our LP modeling language is termed technical coefficient. Technical coefficients address the demand for the activities concerning the restrictions and deliver the values of each activity for the goal function. Therefore, in other words, technical coefficients link the activities with restrictions and deliver the values for the right-hand side of the LP equation system (for left-hand side see C^1). Yet, in a rural ecosystem study, it is impossible to measure every condition of the system. Therefore, a few selected and well chosen indicators – would be sufficient to summarize the complex information (Farrow and Winograd 2001). For example the expansion of cash crops on large agricultural areas, the domestication of wild medicinal and aromatic plants, and introduction of horticulture are innovations adopted by farmers that have spread over time (Nautiyal et al. 2001a,b). Such decision making behavior for the scenario development at micro level is important (Nelissen 1991). Therefore, there is an increasing interest in micro-oriented interdisciplinary research, which indicates that household processes have a large influence on economic and ecological processes (Klevmarken 1983; Moody 2005).

Technical coefficient in view of ecological restriction (T^5 C^5):

Each activity has also been well evaluated in view of ecological indicators such as biodiversity, soil quality, erosion, water quality, nutrient cycling, and air pollution. The outcome of this evaluation, in current LP modeling language, is termed as bio-technical coefficient. Bio-technical coefficients address the effects of the activities on the ecological parameters. Bio-technical coefficients in the LP equation systems link the activities with ecological parameters and deliver the values for the right-hand side (for left-hand side see C^1).

Scenario results/outcome of the model (T^6 C^6): Scenario results in terms of production, economic and ecologic viewpoints emerge from farmers' decisions under the specific scenario that representing a specific set of drivers (for detail please see C^1). Results show which production system farmers would choose under specific circumstances, what is the income anticipated from the decision and what is the ecological performance of the resultant landscape management. Results would show the ex-post as well as the ex-ante analysis, the latter has great importance in terms of the impact of policy options. Economic results could be produced in the form of tables and figures, while spatial and temporal dimensions of the ecological results could be produced in GIS maps. The linkage between economic and ecological outcome could be demonstrated by means of tradeoffs.

Superimposing of theory and concepts are summarized in table 2 concerning the theoretical and conceptual model dimensions of the landscape research.

Conclusion

From the empirical study, it was observed that the real world is a complex system concerning landscape management. The key for understanding changes in land management is the knowledge of farmers' decisions. Farmers make decision and they decide not only for their economic prospects but also the ecological performance of the resulting land management system. Farmers are influenced by several drivers and follow many different goals that are economic, cultural, religious or ecological or region-specific in nature. Science has to deal with both options/activities - those that are already established in the landscape and those in the process of development by scientists. To understand effects of alternative options, they must be evaluated from a socioeconomic and ecological viewpoint. Until now, much of the scientific work has been carried out on investigating parts of this complex system, but now a few models are available to integrate all the components

Table 2. synthetic vision of theoretical and conceptual models developed for the mountains of the Indian Himalayan region (Code 'T' for Theoretical model and 'C' for Conceptual model). $T^1, T^2, T^3 \ldots T^6$: Modules of theoretical model development as described in Fig. 7; $C^1, C^2, C^3 \ldots C^6$: Modules of conceptual model development as described in Fig. 4)

Code	Evaluative dimension	Aim	Character	Theoretical model (Theory)	Conceptual model (Concept)
T^1 C^1	Driving forces	Aim to understanding the influence in the farmer/agent behaviour/decision	Influence human activities	These are the driving forces influence farmer to behave	These are the economic and ecological restrictions and farmer act accordingly
T^2 C^2	Decision maker	To understand his behaviour and model his decision	Mind setup of the farmer to behave	He behave according to his requirements (socioeconomic and ecological goals) and influences of the driving forces	Solution could be provided to maximize his income and control of farm resources and other constraints (regulate in view of the ecological perspective)
T^3 C^3	Options in farm-management	Scope of activities	Choice to choose/ Offer all options	These are the options available with farmer	These are the farmers' activities and he has to maximize the possibilities for the best output among them
T^4 C^4	Contribution to income and socioeconomic indicators	To assess the impact of farmers' options from an economic viewpoint	Evaluation of all socioeconomic parameters of each option	To evaluate the monetary benefit from each option and demand on farm resources	Provide technical coefficients of activities (right hand side of equation system)
T^5 C^5	Assessment of ecological indicators	To assess farmers' options from an ecological perspective	Evaluation of all ecological parameters	Impact assessment of farmers' options on environment (indicator based)	Proved bio-technical coefficients of farmers' activities (right hand side of equation system)
T^6 C^6	Integrated evaluation	To simulate production, economic and ecological effects of farmers' decision under specific circumstances	Integrated analysis	Scenario results	Model outcome in form of tables, figures, GIS map and tradeoffs

of this complex system. The analysis and the procedure up to the development of the conceptual model is based on the detailed field-level data collected from the Himalayan region over a period of twelve years. This is noteworthy as excluding this approach in designing and developing the theory and concepts has been identified as the main reason for the failure of models. Yet, to understand the real world complexities, an integrated interdisciplinary approach was followed in the current research. The conceptual model system MODAM developed for the Himalayas, is more of a philosophy rather than a pure software solution. Modeling starts much earlier when thinking process about the model starts and comprehends a complex process of preceding research coordination. From a scientific point of view, the challenge is to bring the natural as well as social and economic disciplines together to make research integrated and interdisciplinary. Developing a software solution marks the end of a long modeling process.

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