Integrating GIS and Multicriteria Decision Making Techniques for Land Resource Planning

Arabinda Laskar

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By

Arabinda Laskar

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Thesis Assessment Board

Chairman: Dr.Ir. R.A. De By
External examiner: Drs. W. Quak
IIRS member: Dr. P.S. Roy
Supervisor: Ms. Y. Sun

Supervisors:

Ms. Y. Sun (ITC)
Mr. C. Jegannathan (IIRS)

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION ENSCHEDE, THE NETHERLANDS

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Abstract

‘Land’ plays multidimensional role in maintaining many global processes, therefore sustainable planning and management of land resources is an important issue at the global forum. The process of land resource planning and associated decision-making invariably involves multiple objectives, multiple criteria and multiple social interests and preferences. Such complexity necessitates a systematic approach to the decision-making process to accommodate the multiplicity and multi dimensionalities of the problem to improve the reasonability of decisions and to justify the actions to be taken. Application of Geographical Information Systems (GIS) is widely spread in resource inventory and mapping, however, the potential of GIS for planning and decision-making couldn’t be utilised fully due to it’s limited ability to represent judgements, values, arguments and opinions of the decision makers. Integrating GIS and Multicriteria Decision Making (MCDM) methods can overcome these limitations.
In the present research, an approach has been taken to integrate Multi Criteria Decision Making (MCDM) techniques in a GIS environment to address the issue of land suitability assessment and allocation for competing land uses. Two different MCDM approaches: Spatial Analytical Hierarchy Process (Spatial- AHP) and Spatial Compromise programming (Spatial- CP) are applied for land suitability assessment. Integration of MCDM techniques in GIS provides mechanism to represent combination of facts and value judgements and helps to over come the limitations of conventional GIS. The approach proposes in this research makes use of expert knowledge extensively to model land use suitability. Multivariate statistical analysis is used for multiobjective conflict resolution and to find the allocation pattern. The results identify a land use pattern that satisfy the suitability criteria for the conflicting land uses, minimises the likelihood of conflicts among them and also maintains spatial contiguity and compactness to prevent land fragmentation. The methodology is capable of providing useful results for conflict resolution with a minimum data and also understandable to laymen, while yielding mathematically rigorous results at the same time. An attempt is made to develop a prototype system integrating all the components. The applicability of the proposed methodology is demonstrated with a case study.

Keywords: Geographical Information System, Multicriteria Spatial Decision Making, Land resource planning, Multivariate statistical analysis, Expert knowledge, Spatial Decision Support Systems

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List of abbreviations

AHP----------- Analytical Hierarchy Process
CP------------- Compromise Programming
DBMS-------- Database Management System
DSS----------- Decision Support System
GIS------------ Geographical Information System
MCDM------- Multi Criteria Decision Making
MCE---------- Multi Criteria Evaluation
PCA----------- Principle Component Analysis
RS------------- Remote Sensing
SDSS---------- Spatial Decision Support System
PCM---------- Pairwise Comparison Matrix
CR------------- Consistency Ratio
IMSD--------- Integrated Mission for Sustainable Development
FAO----------- Food and Agriculture organisation

1. Chapter I: Introduction

Global concern about food security and quality of life for future generations and growing awareness of environmental degradation pose serious questions to the achievements of science. For the last 150 years or so, our planet has undergone a rate of change unprecedented in human history. The industrial revolution of nineteenth and twentieth century has permanently altered the pattern of human development and rates of consumption of the world's resources (Blowers, 1996). Similar to any other resource management tasks, land resource planning also involves specialized resource allocation problem and the challenge is to formulate complex, spatially and temporally interdependent patterns of uses to achieve multiple, non-commensurable and frequently conflicting goals. Solving problems and making decisions about the sustainable use of land resources demand for integration of data and knowledge from a wide spectrum of disciplines.

A systematic approach to decision analysis is required to improve the quality of the decisions and to justify the actions to be taken. Technological innovations and advancement in the field of Remote Sensing (RS) and Geographical information systems (GIS) provided huge amount of raw data in the form of resource inventory and mapping. However to be useful for decision making the data need to be processed to obtain relevant information. Broadly two types of information are associated with the spatial decision making process: geographical information and information about the decision maker's preferences. In this regard a framework that integrates the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis with the capabilities of Multicriteria Decision Making (MCDM) techniques for aggregating the geographical data and the decision maker's preference, shows immense potential to address spatial decision making problems (Malczewski, 1999). Such integration facilitates the design and development of Spatial Decision Support systems (SDSS) to improve the effectiveness of decision-making by incorporating decision maker's judgements and computer based programmes within the decision making process.

1.1. Problem Definition

Expanding human requirements and socio-economic activities impose increasing pressure on land resources, thereby creating competition and conflicts in their uses. This in turn results into sub optimal utilisation of these resources. The process of land resource planning and decision making aims at identifying the most appropriate spatial pattern for future land uses according to specified requirements, preferences or predicators of some activity. Involvement of multiple criterions, objectives and wide range of stakeholders makes the process complex and multidimensional in nature. These complexities necessitates a systematic approach to decision analysis in a framework that supports advanced spatial data processing techniques as well as facilitates incorporation of knowledge, experience and judgements in the process. Integration of MCDM techniques with GIS based spatial analysis functionalities can provide an efficient mechanism to explore complex decision problems in an interactive and recursive fashion.

1.1.1. Need for sustainable land resource planning

The concept of competing relationship between economic development and environmental protection (Daly, 1987), bought these two issues at the focus of all global, national, regional and local policies and planning through out the world. Realisation of the fact that, this idea of opposite poles will not lead the humanity to a long time survival, as well an effort to discard this believe the concept of 'Sustainability' was introduced for the first time to the international forum by Brundtland Commission (WCED, 1987). The importance of sustainable land resource management is duly recognised by the world community and the seriousness of the issue can be judged from the fact that, 1992 United Nations Conference on Environment and Development (UNCED, 1992) completely dedicated the 'Chapter 10' of its 'Agenda 21' to this issue. Evaluation of land resources, their management and planning has become an important component of sustainability analysis through out the world (Hall et al., 2000). The socio-economic needs of rapidly increasing populations and the consequent increased competition by different types uses emphasize the need for more effective land use planning and policies (Antoine et al., 1997). By now it is widely accepted that land resource planning should be considered as a decision-making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits" (UNCED, 1992). The prerequisites for the wise and sustainable use of land resources are the collection, management, processing and dissemination of information to planners, administrators and policy makers. The decisions made in this regard should be based on comprehensive and quantified assessment of potentials and development possibilities of the land resources with due consideration to the biophysical, environmental and socio-economic factors, as well as the space and time dimensions of sustained land use (Antoine et al., 1997). Innovative and efficient computing technologies allows for systematic collection and timely sharing of data. However transformation of available data into information and knowledge requires human intervention to add values so as to make some sense out of it and to put into some use. To address such a complex issue a systematic approach of decision-making is required to accommodate the multiplicity and multidimensionality of the problem.

1.1.2. Land resource planning - a spatial multicriteria decision problem

Successful formulation of land use strategies requires characterisation and comparative analysis of competing land uses, to ensure that the selected land use correctly match the nature of land resources (Zhu et al., 1996). Such a process involves: identification of suitable land uses, assessing the suitability of land for each competing uses, identification and resolving of conflicts among the competing uses for spatial allocation. All these processes take place in a spatially defined context and involve multiple criteria and multiple objective decision-makings. Hence demands for informed decision analysis from the part of decision makers and planners so as to create a negotiation platform for consensus among the stakeholders. Therefore the decisions made with respect to utilisation of land must be clear and transparent to the stakeholders and the actions need to be justified. Prerequisites for the construction of such negotiating platforms are: mobilisation of existing expert knowledge, integration of information of different format; resolution and thematic content, development of tools for modelling land utilisation options, development of interactive communication techniques between analyst and decision makers/users. It also widely recognised and accepted that land resource planning need to consider the different dimensions of sustainability: ranging from biophysical dimension to economic and social dimensions The biophysical dimensions of sustainability relate to the long-term maintenance or enhancement of the productive capacity of the resource base whereas economic and social dimensions relate to the long-term economic viability of resource utilisation systems and social development (Byerlee et. al., 2001).

For effective and efficient decision-making the prime requirement is the data on various facts. In the subsequent stages of the process, the original data are interpreted and analysed to produce information useful to those involved in the planning process. The information requirement associated with the planning process can be broadly categorised in to two classes: 'hard' information and 'soft' information (Malczewski, 2003). The hard and soft information is also sometimes referred as objective and subjective information, respectively. The former are derived from reported facts, quantitative estimates and systematic opinion survey, for example, census data, remote sensing data, meteorological surveys, etc. The soft information represents the opinion (preferences, priorities, judgements, etc.) of the interest groups and decision makers. This implies that GIS must have the capabilities of incorporating the soft data into the conventional map-based GIS operations to be useful in answering questions related to land resource planning and management. In this regard it is suggested that the integration of processing capabilities of GIS with the structured decision-making approach featured by Multi Criteria Decision Making (MCDM) techniques provides a platform for incorporating preferences in the planning / decision making process (Jankowski, 1995). Despite the fact that most of the spatial decision problems are multicriteria in nature, involving several dimensions and conflicting values, the process of multicriteria decision analysis is not well established or effectively integrated into the field of spatial analysis and GISs (Malczewski, 1999).

1.1.3. Integration of GIS and MCDM techniques

Two distinctive areas of research, GIS and MCDM can benefit form each other. GIS techniques and procedures have an important role to play in analysing MCDM problems through automating, managing and analysing a variety of spatial data for decision making. Although an increasing number of GIS are described as systems for supporting spatial decision problems, most of the GISs lack the kind of spatial analysis required by decision makers. On the other hand MCDM methodologies provide a rich collection of techniques and procedures to revel decision maker's preferences and to incorporate them into GIS based decision-making. Integration of these technologies through an interactive and user-friendly interface provide the framework of spatial decision support systems (SDSS) and help to improve the effectiveness of decision making by incorporating decision makers judgements and computer based programmes within the decision making process.

1.2. Research Objectives

The main objective of this research is to explore the potentials of spatial multicriteria decision-making methods for land resource planning. In the process research focuses to develop a methodology for optimal allocation of competing land uses by integrating multicriteria decision-making techniques in a GIS platform.

- Developing a methodology for optimal allocation of competing land use alternatives using geo-spatial modelling integrated with multi-criteria decision-making techniques.

1.3. Research Questions

To meet the objective of the study the following research questions need to be addressed:

- How to decide the potential land use alternatives?
- How to incorporate expert knowledge and decision maker's judgements in the process?
- Which MCDM technique(s) should be adopted in the suitability analysis model and optimal allocation model for competing land use alternatives?
- How MCDM technique(s) can be integrated with geospatial modelling to design a prototype of Spatial Decision Support System?

1.4. Structure of the thesis

The present research is elaborated in five chapters. Chapter 1 deals with the basic reason behind this research, its objectives and research questions. This chapter also gives a brief overview of the case study area. Chapter 2 explores the existing literatures related to the various components associated in this research. This chapter also presents a brief theoretical background of the main concepts involve in this study: sustainable land resource planning, spatial multicriteria decision-making and multivariate statistical analysis. Chapter 3 deals with the development and evaluation of the proposed methodology in the form of a case study. In this chapter we addressed the first three research questions with practical example. We also discuss about the findings from the case study. Chapter 4 gives the conceptual design of the spatial decision support system that can be developed utilising the methodology presented in this research. Finally Chapter 5 describes the conclusions and recommendation by addressing the research questions in a focused manner.

1.5. Assumptions and scope of the research

- In order to develop and test the methodology, a case study has been chosen, for which the required data and information are available. The experts, who were consulted during the study are well aware about the study area, hence will be able to provide sufficient knowledge required to develop the methodology.
- Though a limited number of socio-economic factors were considered for the case study due to limited availability of data, the present study assumes that the identified objectives, decision factors and decision the decision outcomes are valid for the study area.
- Though remote sensing and GIS play important role in input preparation and spatial analysis the, focus is made to develop a methodology to integrate MCDM techniques in GIS environment.
- The methodology developed can be extended to any spatial multicriteria decision-making process involving resource management.
- The study can be extended to incorporate several other aspects associated with land resource planning and can provide a platform for development of decision support system for land resource planning.

1.6. The case study

A case study is taken up to demonstrate the concept. The area chosen for the current research is Banduan block located in Puruliya District, West Bengal State, India. The boundary of the study area lies between the latitude of 22° 42′ N and 22° 58′ N and longitude of 86° 25′ E and 86° 40′ E (Fig: 1.1).

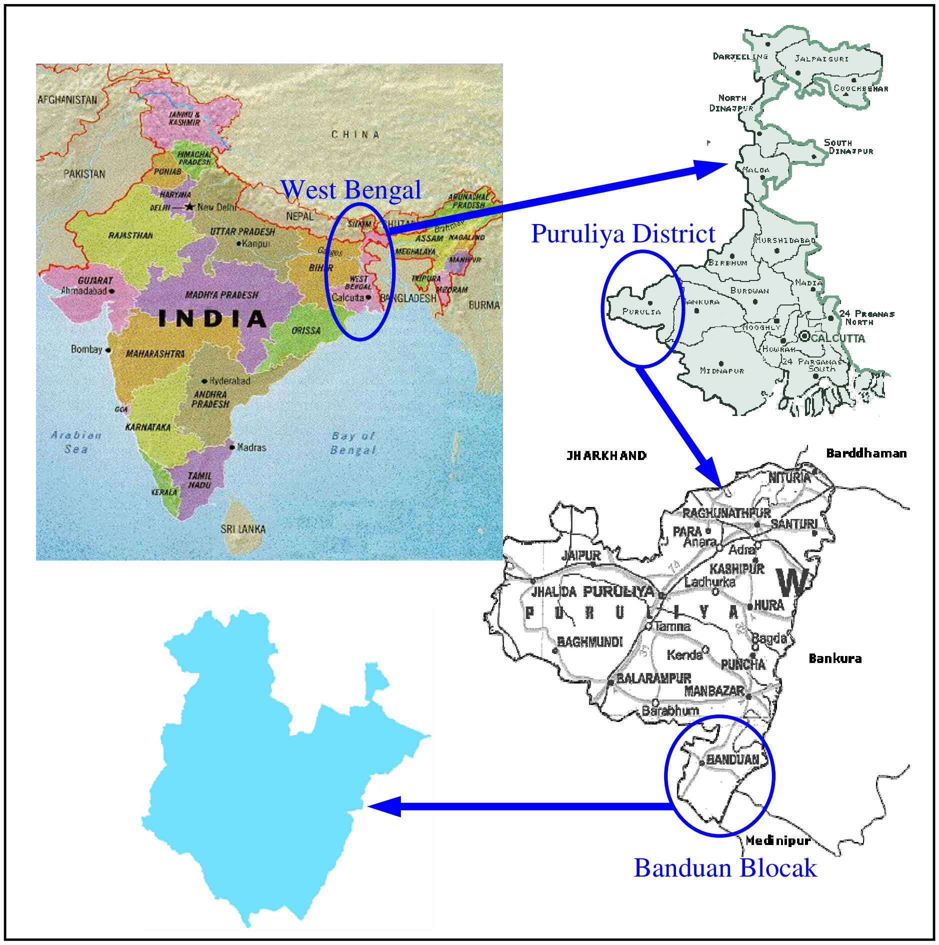


Figure 1.1: Study area location

The study area is characterised as drought prone with an average annual rainfall of 1300 mm and with 112 rainy days during May to September. The topography of the area consists of undulating plains with isolated mounds and hills mixed with long starches of flat area. The soil is of poor quality with very low fertility. The land is facing severe rate of degradation due of to improper management practices. Majority of the population leave in the rural area and depend on poor agricultural production. Forest is another major natural resource and rural population rely heavily on the forest for meeting their day-to day needs and also partly for earning their livelihood.

The prime objective of this research is to develop a generic methodology that can be applicable to any study area. However for the initial development we have to have a test site. One of the main considerations of selecting the study site was the availability of several experts from different discipline who are well acquainted with the study area. A pilot project was also carried out for the same study area to develop action plan for wasteland reclamation at Indian Institute of Remote Sensing (IIRS), India. Spatial and non-spatial data for several themes are available for the study area. Most importantly the study area characterise a typical degraded landform and the socio-economic activities in the study area revolves around land resources. Such characteristics suit the selection of the area for the case study to demonstrate the applicability of the methodology.

Despite of gaining importance and widespread acceptance of multicriteria analysis based geo-spatial modelling as a tool for decision-making in land resource management and regional planning, it is still in the infant stage in India. The major initiative by Government of India in the form Integrated Mission for Sustainable Development (IMSD) also suffers from such limitations in the methodology for resource evaluation and planning. The introduction of technical innovations in the IMSD methodology, such as data integration and spatial analysis tools, coupled with GIS and MCDM techniques can contribute significantly in aid of decision support (Harmsen et al., 2002). In this respect this study will have a significant contribution to explore the potentials of this approach to address the issue of land resource planning and management.

2. Chapter II: Literature Survey on Spatial Multicriteria Decision Making

2.1. Introduction

Since the arrival of the concept of sustainable development on the worldwide stage in the 1990s, an awareness regarding the dimensions of sustainable development has been paramount in the minds and actions of many. By now it has been widely recognised that the translation of natural aspirations of the people's well-being in terms of social and political objectives for sustainable development such as poverty alleviation, agriculture and food security, sustained population growth, equitable and secure access to land, natural resources and environmental management etc. are very closely linked to factors of land and land resource management (Nino-Fluck, 2000). Consequently the perceived wisdom in the approach to evaluation, use and management of land resources is changing rapidly and dramatically. Land resource managers and policy makers are forced to recognise the finite extent of fertile land, the seemingly insatiable demands of a growing human population (Smyth et al., 1993) and the need for strategies that addresses characterisation and comparative analysis of competing land uses (Healey et al., 1988) to ensure that the land use is correctly matched to the nature of land resources.

Solving problems and taking rational decisions in such a complex domain need integration of information, knowledge and expertise from a wide domain of disciplines and also needs some kind of support mechanism that can assist the planners and decision in informed and rational decision-making. Recent advancement in information technology has played a significant role in decision analysis related to land resource management, for example geographic information system (GIS) have been used to develop land use suitability models to assist the choice of land use in land use planning (Zhu et al., 1998). However application of such technology in isolation cannot address the complexities associated to resource management (i.e. land resource management) and fails to extend full support in decision-making. Being a problem with multiple dimensions involving multiple criteria, multiple and conflicting objectives land resource planning is considered as a multicriteria decision making (MCDM) problem that needs specialized tools and techniques that can support a systematic approach of decision analysis. In this regard integration of GIS and MCMD technologies in the form of spatial decision support system (SDSS) holds immense potential in planning and decision-making for land resource management (Fischer et al., 1996; Matthews et al, 1999; Joerin et al., 2001).

2.2. Land resource planning and Decision making

Sustainable land resource planning can be defined as " instruments to set land use policies, to implement these policies for the right location of the various land uses and for the improvement of the spatial and physical conditions on the long term while meeting the needs and aspirations of the present generations" (Van Lier, 1994). It involves the assessment of physical, socio-economic, institutional and legal potentials and constraints with respect to an optimal and sustainable use of land resources and empowers people to make decisions about how to allocate the resources (FAO & UNEP, 1999). Planning can be referred as " the art of organizing Space"(Kozlowski, 1988) and bears a very close resemblance to the decision making process which is oriented at balancing future goals and present inadequacies (Pettit et al., 1999, Jankowski, 1989). Planning can be considered as a tool that supports decision making by assisting the decision makers (governments, resource managers, stakeholders) to use resources in such a way that current problems are reduced and specific social, economic and environmental goals are satisfied (Bronsveld et al., 1994) and the same concept can also be extended conveniently to the domain of land resource planning. Sustainable land resource planning and management has been also defined as “a system of planning and/or technologies that aims to integrate ecological with socio-economic principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity” (Hurni, 2000).

UNCED Agenda 21, clearly states that land resource planning should be considered as a decision-making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits” and the decisions should be based on comprehensive and quantified assessment of potentials and development possibilities of the land resources with due consideration to the biophysical, environmental and socio-economic factors, as well as the space and time dimensions of sustained land use”. The selection of land uses for a land evaluation depends on government development objectives for the area concerned and on possible solution to existing land use problems. Each land use has specific biophysical requirements with respect to land conditions. In the matching procedure of land evaluation, these biophysical requirements are compared with the relevant combinations of land characteristics of a land resource map (Bronsveld et al., 1994). In consideration of the abovementioned observations the aim and objective of land resource planning can be defined in terms of solving/reduction of land related conflicts through the identification of ‘preferred future land uses’ (FAO, 1994,1995,1996,1997). Three key processes are involved in this process:

1. Evaluating the intrinsic value of the various environmental and natural qualities of land
2. Identifying realistic future land uses
3. Making decisions on the actual allocation of land to suitable land uses

All the above processes take place in a spatially defined context and involve multiple criteria and multiple objective decision-makings and demand for informed decision analysis from the part of decision makers and planners so as to create a negotiation platform for consensus among the stakeholders. Prerequisites for the construction of such negotiating platforms are, among others: the mobilisation of existing expert knowledge, integration of information of different format; resolution and thematic content, development of tools for modelling land utilisation options, development of interactive communication techniques between analyst and decision makers/users. Considering the complexity involved in land resource planning and management, straightforward application of decision-making processes may be too complex for the planners and decision makers to simply learn and apply, rather require some structured tools or methods in the form of decision support system (DSS) for efficient and effective decision-making. DSS can be perceived as a computerised system that assists the decision makers in solving decision problems (Sprague et al., 1982). Advancement in modern information technology can support such effort to a substantial extent and can assist the planners and decision makers for more certain, informed and acceptable solutions through efficient management and analysis of information.

2.3. Information technology in Decision making & planning

Information is of great value, as it can be used to extend knowledge, enhance wisdom and reduce uncertainty. It helps us to understand how the world works and assist us in making better decisions about developments that will affect our circumstances. In natural resource management regime, the planning comprises a structured process in which decision-making and problem solving occur and in both the processes information plays a significant role. Decisions deciding the future state of land utilisation need to be based on the knowledge of the spatial distribution of the potentials for fulfilling the functions of the landscapes related to society's need (Hermann et. al. 1999). The successful outcome of decision making and problem solving within the planning process is dependent on the input information and it's subsequent manipulation and handling. Planning strategies for sustainable land management requires solid base line data on natural resources (soil, physiography, climate, vegetation, land use, etc.) and on socio-economic aspects. GIS and remote sensing play a vital role in linkage and analysis of such data, in particular for detection (direct/indirect), extrapolation, interpretation and monitoring (Godert et. al. 2001). As the complexity of decisions increases, resource managers may increasingly lack the necessary expertise and consequently the capacity to make resource management decisions that integrates wide range of issues involved and need to be assisted through advanced technologies for information acquisition, management and analysis.

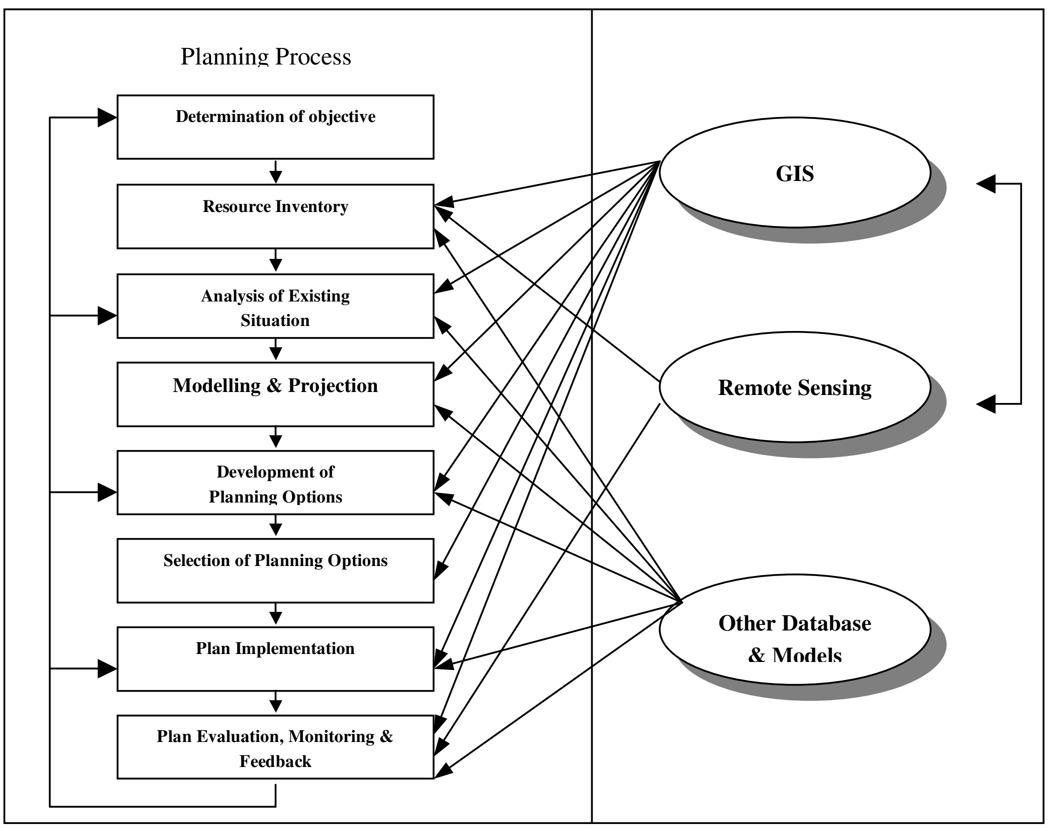


Figure 2.1:Integration of GIS, RS and other database and models into planning process (adopted form Anthony, 2000)

2.3.1. Role of remote sensing and GIS

In the domain of modern resource management, Remote Sensing (RS) and geographical information system (GIS) plays a significant role in compilation, analysis, presentation and monitoring of spatial data. Remote sensing and GIS technologies are of particular relevance to developing countries, where areas of interest are often large, communications are difficult and existing databases are incomplete. Moreover, the requirement for management of the land resources in these areas is particularly of immense interest as many of the world's most fragile and threatened ecosystems are found in these countries (Belward et al., 1991).

As indicated in the Fig: 2.1, in the context of land resource management RS data coupled with field observation are used for resource inventory and analysis of the existing situation. Such information, once integrated in a GIS environment can be used to quantify and analyse the verifiers or the decision factors associated with the decision problem; for example, identification and proper allocation of a set of land use systems for an area can be analysed by overlaying interacting biophysical (slope, soil type etc.) and socio-economic (% land holding, fuel/fodder deficiency etc.) factors. The functionalities of GIS are frequently supplemented through the application of various external models. Remote Sensing and GIS in combination will be an integral part of input preparation and analysis process of the study.

The main focus of this study is to investigate the role GIS and multicriteria decision-making methods can play in spatial decision support and how theses roles can be further strengthened by integrating Multicriteria Decision Making (MCDM) techniques into GIS environment. So at this point it is necessary to investigate how these two technologies from different domain of science contributes in the fundamental process of planning and decision-making and most importantly how a marriage between these two technologies can improve the efficiency and effectiveness of each other. However the focus will be on their application in the domain of land resource planning and management.

2.4. Planning and decisonmaking in the spatial domain

2.4.1. Rational model of decision making process

Planning can be defined as the process of selecting the best, among available alternatives and bears a very close resemblance to the decision making process, which is oriented at balancing future goals, present inadequacies and resources (Jankowski, 1989). Many everyday decisions and compromises are made on the basis of intuition, common sense, chance or all of these. However, sometimes problems of choice are so complex that decision makers (DMs) are not capable of arriving at a logical and rational resolution by using a process consisting merely of intuitive logic and reasoning (Schmoldt et al., 1994). While informal decision-making may result in acceptable decisions in many cases, problems of medium or high complexity need more rigorous and rational appraisal procedures (Youdale, 1983). These complexities necessitates a systematic approach to the decision making process to accommodate the multiplicity and multi-dimensionality of the problem and is also useful to gain a through understanding of the issues affecting the problem (Jankowski, 1989, 1995).
Three major approaches of planning and decision-making evolved over the years (Pettit et al., 1999):

1. Rationalist approach
2. Incrementalist approach
3. Mixed scanning approach

However, it is the rational approach advocated by Batty (1993) and Jankowski (1995) gained the most popularity as the basis for planning and decision making in spatial domain. The fundamental concept behind this model is behaviour rationality of individual and organisational decision-making that asserts the superiority of intellect over empirical experiences (referred by Jankowski, 1995 citing Encyclopaedia Britannica, 1974) However in subsequent period this concept has been supplemented by the concept of bounded rationality and procedural rationality advocated by Simon (Jankowski, 1995). According to the bounded rationality concept individuals and organisations follows satisfying decision-making behaviour based on search activity to meet certain aspiration levels rather than the optimising behaviour aimed at finding the best decision alternative and the concept of procedural rationality focuses on the effectiveness of decision support procedures in search of the relevant decision alternatives.

Rational planning and decision making aims at solving an unstructured or semi structured problem and often involves answering of questions like: 1) what is the problem? 2) What alternatives are available? 3) Which alternative is the best? The different phases and process involved in planning and decision-making process can be modelled and integrated in the form of a general framework.

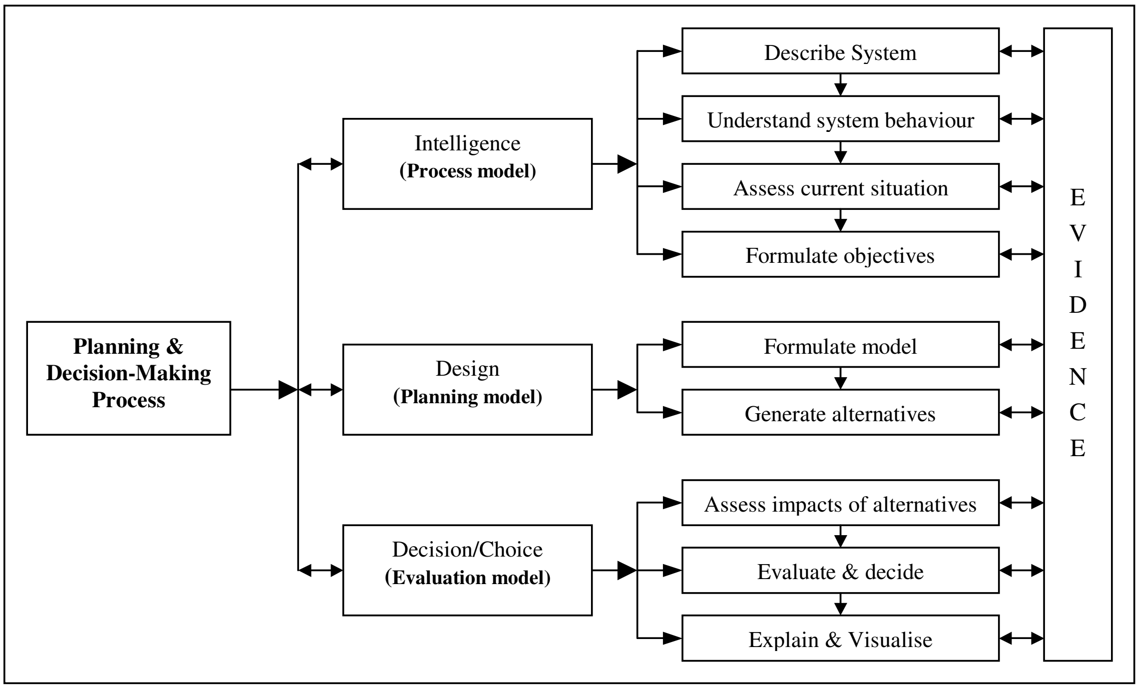


Figure 2.2:Framework for planning and decision making process (adopted from Sharifi et al., 2002a)

Fig.2.2 represents a general framework of planning and decision-making based on Simon's famous three-phase framework of Intelligence, Design and Decision.

1. Intelligence: deals with the problem identification. The discrepancy between the present state and the desired state is recognised as a need and this need is formulated as a problem calling for decision. For example, in the present context the problems associated with the area and the future developmental objectives in terms of alternative land use plan define the problem situation that need decision. Proper understanding of the system behaviour and assessment of the current situation leads to identification of goals and objectives of the decision
2. Design: deals with generating, developing and analysing possible course of action for the problem solution. In this phase feasible alternatives and criteria for evaluating the alternatives are established.
3. Choice: deals with evaluating alternative options and selection the course of action.

2.4.2. GIS in spatial planning and decision-making

In the context of planning and decision-making in spatial domain, spatially referenced data and information provides a geographically referenced basis for the situation analysis. This helps to develop the required intelligence for problem solving, consequently allowing the interpretation of information and subsequent decisions with respect to the 'ground' in real world situations (Kliskey, 1995). This spatial framework helps to impose structure on the otherwise unstructured configuration of resource inventories and provides a form of geographical classification that assist for informed and rational decision-making. To provide a spatial perspective to the decision making process GIS has been used extensively to take data input and to transform them into new information, through overlay and analytical operations (Parent et al., 1987; Malczewski, 2003). However the functionalities of most of the GIS fall short to support the requirements of planning and decision-making tasks (Malczewski, 1999; 2003; Jankowski, 1995; Greetman, 1999).

To implement the framework of rational planning and decision making (Fig.2.2) in a spatial domain to assist in spatial decision making, GIS should be able to address the following four groups of functionality that are generally associated with the logical sequence of spatial analysis: selection, manipulation, exploration and confirmation (Sharifi et al., 2003a). Selection involves the query or extraction of data from the thematic or spatial databases and manipulation deals with transformation, partitioning, generalization, aggregation, overlay and interpolation procedures. Selection and manipulation in combination with visualization can play a very important role as analysis tools. Present day GIS are quite well equipped to perform such tasks and can assist the planners and decision makers in to generate and evaluate development options. Jakowski et al., (1994) cited several early examples of application of GIS in planning and decision-making in different domains: studied by Sperry & Smail (1985) in which GIS was used in the environmental assessment of high-level nuclear waste repository, Buckley & Hendrix (1985) for assessment of site suitability for the land application of liquid waste, however the study by Moreno & Seigel (1988) was significant in expanding the applications of GIS in decision making, though the purpose of the study was environmental assessment, it employed many of the techniques applied in multicriteria evaluation. In most of the are early studies geo-information technology has been widely applied in planning for activities like database management and map presentation, but much less for more analytical and modelling purpose (Greetman, 1999). Some examples of application of modelling and/or GIS techniques to support planning and decision-making in different context are also presented in Longley & Batty (1996).

Several authors in the past, depicted GIS as a decision support technology considering it's capability to provide information for decision making through automating, managing and analysis of spatial data. However several others argue that the current GIS technology does not offer sufficient decision support capabilities (Jankowski, 1995; Laaribi et al., 1996; Malczewski, 1999; 2003). It has been also observed that part the early development and commercial success of GIS were fuelled more by the need for efficient spatial inventory rather than decision support systems and as a result, few systems yet provide any explicit decision analysis tools (Sharifi, 2002b). The lack of enough functionality especially in exploitative and confirmative analysis and evaluation in GIS packages has been the topic of many debates in the scientific communities and as a result techniques to support these steps have gained more attention. In this context several studies have demonstrated the usefulness of integrating multi-criteria decision analysis techniques with GIS in a user-friendly environment.

2.4.3. Failure of GIS in Decision making

From the literatures it is prominent that in the past decision makers were not sound proponents of the use of computer models to support them in making choice and decisions. This observation is even more prominent in the cases of spatial decision-making. Investigation reveals the fact that such dislikes induced due to black box nature of working of majority of optimisation model, limited freedom of choice and flexibility and inability to handle semi or unstructured information in the process of decision making (Van der Meulen, 1992). Some authors considers GIS itself as a form of decision support system (DSS), however GIS is widely recognised as a Computer based system that combines spatial database management, geo/statistical analysis and mapping but not more than that (Van der Meulen, 1992; Laaribi et al., 1996; Malczewski, 1999; 2003). GIS can provide with spatial information for the decision makers but cannot provide any information about the potentials of the information for decision support.

Many criticisms directed towards GIS with respect to their real epistemological position in the field of decision support can be summarised in one phrase: 'are they genuine decision making tools'?? The legitimacy of this question finds it foundation in the following observed facts: though GIS provide decision makers with powerful tools for the processing, management and analysis of spatially referenced data, they lack mechanisms enabling them to incorporate the decision make's preferences and to make a choice in a context of conflicting objectives and multiple criteria evaluation (Carver, 1991; Jankowski et al., 1994; Jankowski, 1995; Malczewski, 1999) For example, most of the today's standard GIS only allow the decision maker to identify a list of sites meeting a set of predefined criteria, through variations in the map overlay process, however they do not offer any mechanism to represent judgement, values, argument and opinions in the process.
Among the requirements for decision analysis that are not satisfied by current GIS software and their analytical functionalities can be listed as follows (Laaribi et al., 1996):

1. Taking into account solutions proposed by decision maker (current GIS accepts only quantitative criteria translating factual information)
2. Allowing for personal preferences (only raster based GIS allow ratios for criteria)
3. Accepting conflicting aspects (GIS allows for constraints but not for conflicting data)
4. Assessment and comparison of feasible solutions (GIS will identify solutions satisfying all criteria simultaneously but will not rank acceptable solutions, which is usually crucial for the decision maker)

These restrictions in modelling of preferences and choice of procedures turn GIS into static environments and consequently reduce their use as a decision-aid tool. To fill these gaps, the adaptation of a heuristic approaches oriented towards the decision maker is absolutely necessary. As an early attempt to solve these problems, several researchers suggested different approaches for integrating sophisticated analytical functionalities to current GIS (Abler, 1987; Goodchild, 1987; Openshaw, 1990, 1991a; Batty et al., 1994). This was aimed to increase the spatial analytical functionalities of GIS and thereby increasing their capacity to assist in decision-making process. Such measures could strengthen the analytical functionality of GIS but still failed to fill the gap between GIS and Decision Support System (DSS). The analytical capability of GIS has increased over the years; however still very few GIS in use today provide clear-cut procedures to support the processes of structured decision-making (Openshaw 1987, 1991b; Densham, 1991; Jankowski, 1995). Until recently very few GIS applications software provided explicit decision analysis tools over and above those offered by map overlay and buffer operations (Diamond et al., 1988; Carver, 1991; Malczewski, 1999). Proponents for the use of GIS and the wider utilisation of geographical information in spatial planning often state that GIS will assist better decision-making but fail to identify how. For example, rigorous analysis of wee controlled data can certainly perform part of the convincing argument when making a case for site selection process, but this is absolutely of no guarantee that the site will be chosen by the decision maker. The need for incorporating explicit decision support procedures in resource management was realised from the reorganisation that decision about the allocation of natural resources happen over a broad spectrum of management levels, involves multiple objectives and criteria and often require input from a diverse group of persons.

Decision problems are rarely based on a single decision criterion and single scale of measurement. In such cases it is impossible to make decisions based on intuition and limited knowledge, with out considering a more rational or integrated approach (Schmoldt et al., 1994). Multicriteria decision making (MCDM) techniques are considered as a promising framework for planning and decision-making process as they have the potential to take account of conflicting, multidimensional, incommensurable and uncertain effects of decisions (Ananda et al., 2003). Multicriteria evaluation (MCE) is one of the most common GIS based strategies that have been designed to facilitate decision making in site selection, land suitability analysis, resource evaluation and land allocation (Voogd, 1983; Malczewski, 1999). Embedded in a GIS environment these techniques provide the framework of a spatial decision support system (SDSS), that aims to improve the effectiveness of decision making by incorporating decision maker's judgements and computer based programs within the decision making process (Bishop et al., 1991; Carver, 1991; Jankowski et al., 1994; Jankowski, 1995; Malczewski, 1999, 2003).

2.5. Survey on MCDM methods

Multi-Criteria Decision (MCD) problems generally comprises of a set of alternatives which are evaluated on the basis of conflicting and incommensurable criteria of quantitative, qualitative or both in nature (Malczewski, 1999). Land use decisions are typically complex owing to the unfavourable tradeoffs inherent in protecting or developing specific lands and differential impacts on various stakeholder groups. In decisions concerning land resource management, planners require to investigate solutions that go well beyond a simple request to locate spatial objects. Rather it deals with choosing an appropriate site for some activity like for example identifying scenarios for future land development. Such decision reaching problems do not lend themselves to linear processing but require a global method of processing, where it takes all the facts into account. In the domain of land resource planning, Multi-Criteria Decision Making (MCDM) approach is considered potential because of its demonstrated ability to integrate multiple criteria, preferences of different groups, expert's knowledge, with-standing spatial; non-spatial and inexplicit data from various sources. However the most significant characteristics of these methodologies is that they are transparent to the participants. Such methodologies make it possible to integrate land use information in knowledge structures and networks, and opens prospects for improved land use planning to investigate a number of alternatives (choice possibilities) in the light of multiple objectives (criteria) and conflicting preferences (priorities) (Bantayan et al., 1998).

Many literatures are available in the domain of MCDM, also on its merits and demerits, however they are mostly used in a non-spatial domain (Keeney and Raiffa 1976; Saaty, 1980; Malczewski 1999; Marjan 1999). The MCDM methods can be broadly categorized into two groups as MADM (Multi-Attribute Decision Making) and MODM (Multi-Objective Decision Making). MADM is concerned with choice from a moderate /small size set of discrete actions (feasible actions) while MODM deals with problem of design (finding a near-optimal solution) in a feasible solution space bounded by the set of constraints (Jankowski, 1995). Both MADM and MODM problems can be further categorized into single-decision maker problem and group decision problem, which intern subdivided into deterministic, probabilistic and fuzzy decisions (Malczewski, 1999). The MCDM techniques can also be categorized depending on the level of cognitive processing demanded on the decision maker (DM) and the method of aggregating criterion scores and the DM’s priorities (Jankowski, 1995). According to the cognitive processing level two classes of MCDM techniques can be distinguished: compensatory and non compensatory. The compensatory approach is based on the assumption that the high performance of an alternative achieved on one or more criteria can compensate for the weak performance of the same alternative on other criteria. The compensatory approach is cognitively demanding, as it requires the DM to specify criterion priorities expressed as cardinal weights or priority functions. Under the non-compensatory approach, another criterion’s high score cannot offset a low criterion score for an alternative. The alternatives are compared along the set of criteria with out making intra-criterion tradeoffs. The class of compensatory MCDM techniques can be divided further, according to the method of aggregating criterion scores and the DM’s priorities, into two subclasses: (1) Additive techniques (2) Techniques bases on ideal point approach

2.6. Spatial Multi Criteria Decision making

Conventional multiple criteria decision making (MCDM) techniques are mostly non spatial in nature and subjected to the assumption that the area under consideration is spatially homogeneous. This assumption makes such techniques unrealistic as in many cases evaluation criteria vary across the space (Simonovic, 1989). The most significant difference between spatial multicriteria decision analysis and conventional multicriteria decision analysis is the explicit presence of spatial component and hence requires data on the geographic locations of alternatives and /or geographical data on criterion values (Malczewski, 1999). The decision making process is supported through data process using MCDM and GIS techniques. This framework integrates the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis and the capabilities of MCDM techniques for aggregating the geographical data and the decision maker’s preferences into unidimensional value of alternative decisions.

The large number of factors necessary to identify and consider in making spatial decisions and the extent of interrelationships among these factors causes difficulties in decision-making. To this end the integration of GIS and MCDM techniques facilitates in acquiring data and processing the data to obtain information for making decisions. This supports the decision maker in achieving greater effectiveness and efficiency of decision making while solving the decision problem. It is argued that the combination of GIS and MCDM provides the decision maker with support in all stages of decision-making, i.e. intelligence, design and choice (Fig. 2.2).

2.6.1. Framework of Spatial multicriteria decision making

Based on the general classification of MCDM problems, the spatial multicriteria decision problems can be subdivided in to two fundamental categories: spatial MADM and spatial MODM. In this research we will be dealing with multicriteria land suitability analysis, which is a typical spatial MADM decision problem. So at this point we will discuss the fundamental of spatial MADM approach with reference to this example.

Like any other spatial MADM problems in multicriteria land suitability analysis also individual land uses are modelled explicitly (Zhu et al., 1996) based on different set of criteria/factors to determine the potentially suitable areas and to quantify their degree of suitability.

To formalise the issue let us take an example, of a set of alternatives X, defined as decision variables.

$$X = \{ x^k \mid k = 1,2,3,\ldots\ldots\ldots.K \}$$

The alternatives are represented by the set of cells or pixels in a raster GIS database or a set of pints, lines or/and aerial objects in a vector GIS. Though the kind of spatial analysis involved in spatial MCDM is possible with both raster and vector GIS, a raster GIS is preferred over a vector considering its wider mathematical capabilities (Pereira et al., 1993).

In a raster GIS, each grid cell or pixel (i.e. the smallest measurable unit in the database) is taken as an alternative to be evaluated in its quality or appropriateness for a given land use, and the attributes associated with that pixel in each thematic layer represents a criterion for the process of evaluation.

So, the set of all pixels in a given GIS database, X with total K pixels can be represented as (Pereira et al., 1993):

$$X = \{ x^1, x^2, x^3, \ldots\ldots\ldots, x^k \}, \qquad \mathbf{k = 1,2,3,\ldots\ldots\ldots.K} \quad \mathbf{\ldots\ldots\ldots(Equation\ 2.1)}$$

Each pixel is characterised by a set of criteria or decision variables, I, so the kth pixel takes a value *X* for criterion I, and the collection of all possible values in different map layers is defined as follows:

$$x^k = (x_1^k, x_2^k, \ldots\ldots\ldots x_i^k); \qquad \boldsymbol{i} \mathbf{= 1,2,\ldots\ldots\ldots\ldots., I;} \ \forall x_i^k \in X \ \mathbf{\ldots\ldots\ldots (Equation\ 2.2)}$$

Where, the individual x_i^k designate the score of an attribute (map layer) *i* attained by alternative *k*, where *i* = 1,2……, I; *k* = 1,2,……,K. Therefore x^k is a vector of K numbers, assigned to each alternative/cell and synthesising all available information about that alternative in terms of possible incommensurable, quantitative and qualitative criteria and thus defining a 'multiple criteria alternative'(Zeleny, 1982).

The input data for a spatial multicriteria decision problem can be organised in a tabular form and can be visualised as an evaluation table consist of maps or as a map consist of evaluation tables (Fig: 2.3) (Sharifi et al., 2003b).

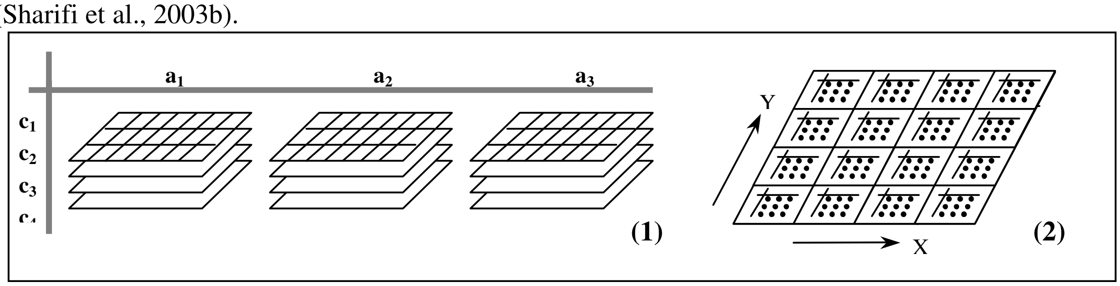


Figure 2.3:Two interpretation of a spatial decision problem (1: table of maps; 2: map of tables)

The evaluation table is referred as decision, evaluation or impact matrix and shows the alternative-criteria relationships. The cell of the matrix contains the measured or assessed values of the attributes associated with particular criteria with respect to the alternatives.

Once the evaluation matrix is generated, the next task is to evaluate the performance of the alternatives with respect to the given decision criterions. In most of the decision related problem, the data in hand are heterogeneous and hence we have to have clear view of how these diverse data can be integrated.

As in the case of our example the objective of the multicriteria evaluation is to evaluate the performance of the alternatives (individual pixels) for a particular land use, the evaluation table of criterion maps need to be transformed into one final score of the alternatives. The function need to aggregate not only the effects of the criterions associated but also the spatial component and such a complicated operation can be simplified to an extent by dividing it in to two operations: 1) aggregation of the spatial component and 2) aggregation of the criteria. These two operations can be carried out in two different sequences as shown in Fig.2.4 as path 1 and path 2.

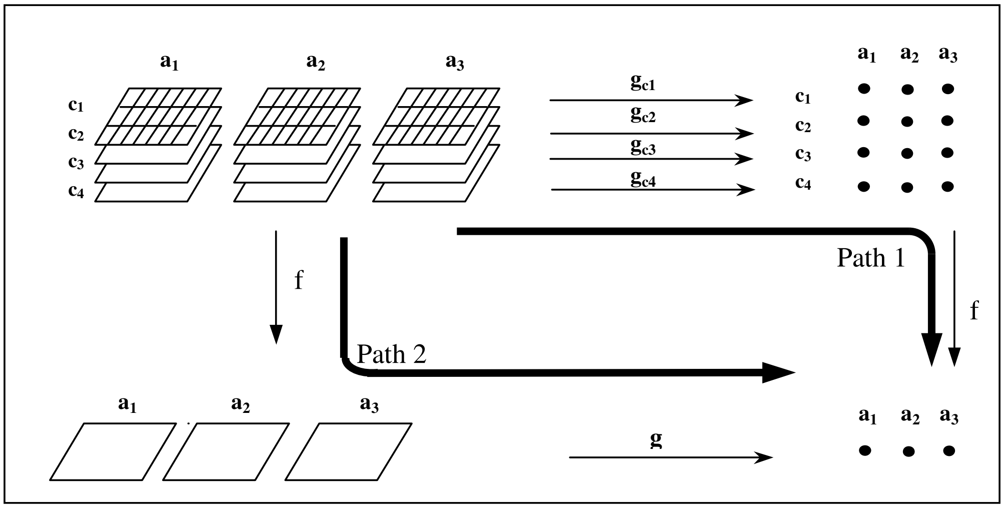


Figure 2.4:Two paths of spatial multicriteria evaluation

In Path1, approach all the spatial elements are converted in to non-spatial element through aggregation techniques and than process them using normal MCDM process. In this case the first step is aggregation across spatial units and second step is aggregation across criteria. Whereas in Path2, approach every decision factor is converted into spatial data and than composite spatial map derived through aggregation and overlay to derive useful information. Path 2 is prescribed where spatial priorities play a key role partially.

2.7. Selection of Spatial MCDM

MCDM approaches are characterised by great methodological diversity and offers different possibilities for implementing in the framework of spatial MCDM. Out of the diverse range of methodologies available under this two class of MCDM techniques we will be using two popular techniques: Analytical Hieratical Process (AHP) and Compromise programming (CP) in this research, hence a brief introduction to this two methods is given in the subsequent sections.

2.7.1. Spatial analytical Hieratical Process (AHP) method

The analytical Hierarchy process (AHP) method, originally developed by Satty (1980), is one of the most flexible and easily implemented MCDM techniques. AHP is a mathematical method for analysing complex decisions with multiple criteria. Its foundation is rooted in the general theory of ratio scale measurement based on mathematical and psychological foundations. When the AHP method is applied to solve spatial decision problems in a GIS environment it is called spatial-AHP method (Sidiqui et al., 1996). AHP is based on three underlying principles: decomposition, comparative judgements and synthesis.

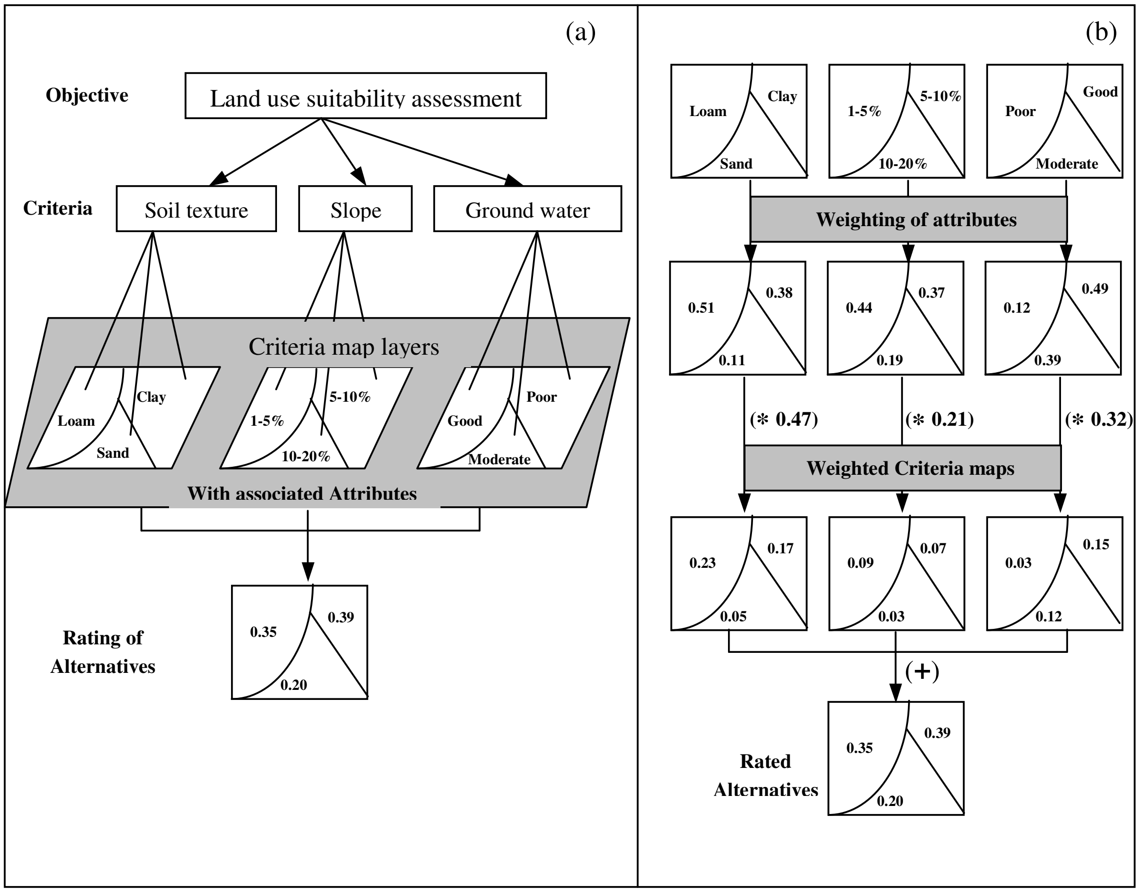


Figure 2.5: AHP process in GIS environment: (a) AHP procedure; (b) GIS based rating of alternatives

Principle of decomposition is applied by first identifying objective, criteria, alternatives and other elements associated with the decision problem and then arranging them in hierarchy (Fig. 2.5). A basic form of a hierarchical model of the decision problem is a pyramid with a broad overall objective (goal) at the highest level. Low levels represent the criteria, sub criteria and the attributes associated with these. For example, Fig. 2.5 (a) shows the hierarchical structure of a hypothetical land suitability decision problem. The highest level represents the objective, i.e. land suitability assessment, the next stage of the hierarchy is the criterions that need to be considered for the suitability assessment and the stage next to that represents the attributes associated with the respective criterions. The suitability of the land will be evaluated based on the relative importance of the elements in each stage of the hierarchy. The hierarchal structuring is a relatively subjective activity, based on decision makers experience, knowledge and understanding of the decision problem. As a rule of thumb a hierarchy should focus on those criteria that are most important to the decision maker and will help to make the required choice. Due to the limited capacity of human mind to compare simultaneously, it is advisable to limit up to a maximum of five to nine branches in any one node of a decision hierarchy to achieve great efficiency and consistency in making decisions.

Once the hierarchy is formed, the principle of comparative judgement is applied to determine the relative importance of the attributes, sub criterions and criterions through pairwise comparison. Elements in a given level in a hierarchy are compared in pairs with respect to a common property or criterion in the level above. The AHP uses a fundamental scale of absolute numbers to express individual preferences or judgements (Table 2.1). This scale consists of nine points, chosen because psychologists conclude that, in general, nine objects are the most that an individual can simultaneously compare and consistently rank. In our example we have calculated the relative importance or weights at two stages: first, for the attributes associated with each criteria (Fig. 2.5-b); second, for the criterions (Fig. 2.5-b). Pairwise judgments are made based on the best information available, and the decision maker's intuition, knowledge and experience.

Table 2.1:The pairwise comparison scale (after Satty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contributes equally to the property
3	Moderate importance one over another	Experience and judgement slightly favour one element over other
5	Essential or strong importance	Experience and judgement strongly favour one element over other
7	Very strong importance	An element is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	Compromise is needed between two judgements
Reciprocal of the above numbers		If an activity has one of the above numbers assigned to it when compared with a second activity has the reciprocal value when compared to the first.

If there are many people participating, multiple judgements can be combined by taking the geometrical mean of individual judgements. The weights derived from a pairwise comparison matrix are called "local weights" with respect to particular criterion or property. After they are weighted by the weight of their criterion element, they are called "global weights". After all judgements have been made and all pairwise comparison matrices have been obtained, the global weights of the elements are calculated. Coming down the hierarchy from the second level, the global weight for each element in one level is computed by multiplying its local weight by the priorities of the criterion elements in the level immediately above and adding them. This global weight is in turn used to weight the local weights of the relevant elements in the level below, and so on to the bottom level. This process in AHP is called synthesis, which result in asset of overall priorities for the alternatives in the bottom level.

The AHP also provides measures to determine inconsistency of judgements mathematically. Based on the properties of reciprocal matrices, consistency ratio (CR) can be calculated. In a reciprocal matrix, the largest eigenvalue (y_{max}) is always greater than or equal to number of rows or columns (n). If a pairwise comparison does not include any inconsistencies, $y_{max} = n$. The more consistent the comparisons are, the closer the value of computed y_{max} to n. A consistency index (CI) that measures the inconsistencies of pairwise comparisons can be written as:

$$CI = (y_{max} – n)/ (n-1)$$

And a measure of coherence of the pairwise comparisons can be calculated in the form of consistency ratio (CR)

$$CR = 100\ (CI/ACI)$$

Where ACI is the average CI of the randomly generated comparisons. As a rule of thumb, a CR value of 10% or less is considered as acceptable.

2.7.2. Spatial Compromise programming

Compromise programming (CP) is a technique based on the displaced ideal concept (Zeleny, 1982). The method is based on the assumption that choice among alternatives depends on the point of reference that is used as optimum or ideal. When this technique is integrated with spatial analysis in a GIS environment, it is known as spatial compromise programming (Pereira et al., 1993; Tkach et al., 1997). Spatial compromise programming (SCP) has the added advantage over conventional compromise programming, that it considering uneven spatial distribution of criteria values in the evaluation of alternatives.

To illustrate the process, let us consider the same example of land suitability assessment. Using this technique each of the alternatives (i.e. the individual pixels in the raster database) can be evaluated for their level of suitability, with reference to the ideal solution by some measure of distance. The ideal solution is the one, which provides the most favorable or preferred value for the each of the criteria considered in the analysis (i.e. the land suitability value derived considering the best attribute values for the respective criterions considered for the suitability evaluation of any particular land use). The distance from the ideal solution for each alternative (each pixel in this case) is measured by what is referred as the distance metric. This value, which is calculated for each pixel, is a function of the criteria value (i.e. relative importance or weight assigned to the attributes for different criterions that need to be considered for the land suitability evaluation for a particular land use system) them selves, the relative importance of various criteria to the decision makers and the importance of the maximal deviation from the ideal solution (Simonovic, 1989).

As discusses earlier (Equation 2.2) a set of alternatives in the GIS database can be described as:

$$x^k = (x_1^k, x_2^k, \dots\dots\dots x_i^k)\ ;\ i = 1,2,\dots\dots\dots\dots,\ \mathrm{I};\ \forall\, x_i^k \in \mathrm{X}\ ;\ \mathrm{X}= \{\ x^k \mid k = 1,2,3,\dots\dots\dots\mathrm{K}\}$$

Where, the individual x_i^k designate the score of an attribute (map layer) *i* attained by alternative *k*, where $i = 1,2\dots\dots, \mathrm{I}$; $k = 1,2,\dots\dots,\mathrm{K}$.

Therefore x^k is a vector of K numbers, assigned to each alternative/cell and synthesising all available information about that alternative in terms of possible incommensurable, quantitative and qualitative criteria and thus defining a 'multiple criteria alternative (Zeleny, 1982).

This vector represents all currently attained levels of the i^{th} attribute (e.g. all slope classes in a map layer of that theme), among these values or levels, there is at least one ideal value that is preferred to all others (e.g. up to 5 percent slope, or gently sloping terrain is most preferred for Agroforestry activities) and the concept generalizes to the multiple criteria alternatives as the set of all individual ideal levels:

$$x^* = (x_1^*, \dots\dots\dots\dots\dots, x_{\mathrm{I}}^*)$$

The vector x^* represents the ideal point, a usually unfeasible alternative, characterized by the best attainable score on every criterion. Using compromise programming all the pixels in the dataset can evaluated for their suitability for a particular land use system based on their multidimensional distance of the ideal point using the following formula:

$$d_p = [\sum_{i=1}^{I} \beta_i^p (x_i^* - x_i^k)^p]^{1/p}, \ \beta_i^p > 0 \text{ and } \sum \beta_i = 1$$

Here,

β_i is the relative importance or weights associated with the criterions (criterions /decision factors that determine the suitability of land for a particular land use systems), it reflects the decision makers preferences concerning the relative importance of various criteria. The parameter '*p*' reflects the maximal deviation from the ideal point. It effects the relative contribution of individual deviation from the ideal point (Ferencsik, 2001). When,

P=1 total compensation is assumed, a decrease of value of one criteria can be compensated by an equivalent gain on any other criterion, i.e. all deviations are weighted equally.

P=2 (the shortest distance) there are only partial compensation, i.e. each deviation is weighted in proportion to its magnitude.

While p ≥10 represent total non-compensatory situation, i.e. the largest deviation ($x_i^* - x_i^k$) dominates the evaluation. In such a case the suitability of a pixel for a given function is only as high as it's lowest score on all criterion or decision factors.

Distance metrics are commonly used in multivariate analysis and classification problem, namely in community ecology and processing of remote sensing images. However there is an essential difference between the use of distance metrics in an MCDM technique, such as Cp and in the fields like ecology and image processing. In MCDM, distance is employed as a proxy for preferential similarity with an ideal choice, in a value laden, judgmental process. The use of distance as a proxy for ecological or spectral similarities, on contrary, is a value neutral affair. This difference is implemented through the inclusion of β_i weights in the CP family of matrices, and also in the transformation of measured physical magnitudes of evaluation criteria into a standardized value scale, elicited from the decision maker.

Data standardization:

Both the approach (AHP and CP) requires standardisation of the input data, the need for data standardization in GIS based land suitability evaluation often arises as a consequent of the need to integrate into the evaluation process data measured not only in different units but also in different scales of measurement, such as nominal, ordinal, interval and ratio scales.

The purpose of standardization can be summarized as (Pereira & Duckstein, 1993):

1. to ensure that all natural scales, some of which may include nominal or ordinal data are converted to a common value scale with interval properties.
2. to account for the possibly non-linear or even non-monotonic character of relationship between natural and value scale.

Data standardization is not designed to make the multicriteria scores independent from the absolute values of the criteria. In fact, the value functions are clearly not independent of a positive linear transformation of individual values.

2.8. Multi objective Decision analysis for conflict resolution

As we discusses in the previous sections, the objectives of land resource management and planning is to find the fitness of a tract of land for the identified uses. In many cases it can be observed that a given track of land depicts suitability for more than one land use type and consequently developing conflicts among the land uses for their spatial allocation. Considering the various types of uses of land and varying their degree of compatibility, it is very important to devise some measure for conflict resolution among the alternative land uses. To solve this problem we need to apply Multiobjective Decision making (MODM) techniques to derive an optimal solution to this problem. There are very few examples of application of multiobjective optimisation techniques in spatial domain can be found in the literature. Examples of two approaches were found in the literatures. The first approach is based on standard linear/ integer programming and the second approach is based on heuristic optimisation. However none of the approaches are free from limitations (Malczewski, 2003). The first approach is subjected to the limitation regarding the number of decision alternatives that can handle at a time. Considering the number of pixels in a raster data set, this approach is not feasible to integrate in a GIS system. The second approach cans over come the issue of number of decision alternatives, but this approach cannot guarantee an optimal solution (Malczewski, 2003).

Examples of multiobjective optimisation techniques in GIS environment are few. An approach that facilitates segregation of land suitable various competing land uses in to homogeneous groups (Eastman et al. 1993) can be useful to address this issue. One notable example that can be found in literature is the multiple Objective Land use Allocation (MOLA) model available in IDRISI. In few other approaches the issue of conflict resolution is addressed through the application of multivariate statistical analysis (Bojorquez-Tapia et al. (1994,1999, 2001). The most significant advantage associated with the second approach is, it requires very minimum spatial data and provided reasonably acceptable results.

Multivariate statistical approach for conflict resolution is based on the concept of classifying the individual pixels (that represent as an alternative to be assigned to a particular land use) in to naturally classifiable distinct groups based on the suitability scores. This will allow the decision maker to estimate the magnitude and likelihood of conflict among the land use systems consequently provide a mechanism for conflict resolution and decision making for potential allocation. One potential approach to achieve this is the application of multivariate numerical classification, through divisive polythetic partitioning (Noy-Meir, 1973; Pielou, 1984). Another approach could be based on hierarchical agglomerative method, but divisive method is considered as it is generally recommended in preference to the other as classification of units (e.g. land use systems) in to broader categories is usually of far greater interest than the interrelationship between pairs of land units (pixels)(Digby et al., 1987).

2.8.1. Divisive polythetic classification

Multivariate techniques provide a rational framework for analysing the similarity of units (suitability groups), which vary with respect to numerous characteristics. Estimated scores of suitability for the respective land use alternatives is used as the basis for grouping to determine homogeneous groups.
Land planners have expressed much concern that the classification must be hierarchical to be of maximum usefulness at different level of planning. A hierarchical form orders classes of objects so that their relationships are known. Each higher level is an aggregation of those and only those classes immediately beneath it. This method is based on fundamentals of cluster analysis, a classification technique for selecting subsets of mutually similar objects from the set of all such objects (cited by

Omi et al., 1979 referring Mather & Doornkamp, 1970). Divisive method operates on the principle of progressive splitting of the whole set of elements in to smaller sets of homogeneous groups. Divisive method has the advantage of use all available information at the initial stage and less likely to be irrevocably led astray by chance (cited by Noy-Meir, 1973 referring Lambert & Dale; 1964, Dale, 1964; Lambert & Williams, 1966; Williams, 1971). A polythetic system is one based on a measure of similarity and dissimilarity applied over all attributes, so an individual is grouped with those individuals, which on the average, it most resembles. Polythetic methods use all the available information at each step more fully. So a combination of both these characteristics makes polythetic divisive classification a statistical tool that can classifies a set of objects by placing them in homogeneous groups in a manner that reflects the interrelationship between the groups. Thus a methodology based on both divisive and polythetic should theoretically be optimal to derive homogeneous groups of the land use systems based on their suitability scores. However only very few such methods have so far been suggested and these are computationally demanding. In a raster GIS database where each pixel is considered as an element of the entire data set need to be classified based on the attribute values they represents. Theoretically, such a classification can be achieved by dividing the whole collection of pixels into two groups in every conceivable way and than by judging which of the way is "best" according to some chosen criteria (should not be misinterpreted as the criteria used for land suitability assessment). However if there are '**n**' pixels in the dataset, there will be (2^{n-1}-1) different divisions to compare with one another (for proof, see Pielou, 1977). Having discovered the best possible division at the first stage, the whole process needs to be repeated on each of the two classes defined at this stage, and so on. Not surprisingly, the computation requirement of such a method is so excessive that it is infeasible unless '**n**' is very small. Several alternative methods were investigated to produce polythetic divisive classification, which is computationally feasible. Among these the approaches the method of deriving polythetic division classification by dividing the ordinated swarm of data received the most popularity.

2.8.2. Ordination Space partitioning

Computational challenge associated with divisive polythetic classification can be addressed by performing an ordination of the data first and then dividing the ordinated swarm of the data points with suitably placed partitions, which is formally called as ordination-space partitioning. The term ordination derives from early attempts to order a group of objects. Nowadays the term is used more generally and refers to an ordering a set of objects in any number of dimensions (preferably few) that approximates some pattern of response of the set of objects (pixels in our case). Ordination helps us to arrange the pixels in some coordinate frame to display their interrelationships. It is useful to perform ordination before classification as the ordinated graph may provide more information about the pattern present in the dataset. Principle Component Analysis (PCA) is one of the simplest and well-applied ordination methods and generally supported by most of the commercially available GIS software. This extracts the set of generalized variables, which accounts for most of the variations in the data and in the process it considers all the available values hence considered as a polythetic entity. A division of the elements according to their values on these components is thus a divisive polythetic classification. When classifications are done, each point in the territory (the alternative pixels) can be easily assigned to a discrete land classes. However if an ordination is used, the points can be arranged in a continuous manner according to the trends (in this case suitability values) recognised. This helps to map the spatial variation and to achieve more efficient partitioning.

In this regard Pielou (1984) suggested a partitioning approach, which was in principle conceived by Noy-Meir (1973) and referred by Pielou (1984) as Noy-Meir's partitioning method. According to this approach the data are first ordinated (with no reduction of dimensionality) by PCA and then the principle axes are broken in to two. The most important issue related to this methodology is deciding the break point.

2.8.3. Deciding criteria for divisibility

According to Noy-Meir's method of ordinated space partitioning the break point is chosen in such a manner that the sum of the (within group) variances of the principle component scores of the group of points on the either side of the break point as small as possible. At this point it also satisfies the condition of getting maximum variance between the groups. In a GIS environment this can be performed through the application of Principle component analysis (Bojorquez-Tapia et al., 2001):

2.9. Integration of GIS and MCDA techniques

Spatial multicriteria decision making (MCDM), is a process that combines and transforms geographical data into a decision. The process consists of procedures that involve the utilization of geographical data and preferences according to specified decision rules. Most of the real life spatial decision problems can be characterised as semistructured problems and requires interaction between decision makers and computer-based systems (Malczewski, 1999). Integration of GIS based data processing and analysis techniques and multicriteria decision analysis techniques in a single platform provide a framework for spatial decision support system (SDSS). Such integration improves the effectiveness of decision-making by incorporating decision maker's judgements and computer based programmes with in the decision making process.

A number of frameworks for integrating MCDM techniques in GIS environment have received considerable attention in the GIS literature (Janssen & Rietveld, 1990; Carver, 1991, Eastman et al, 1993; Jankowski et al., 1994; Jankowski, 1995; Sharifi et al., 2003a). One of the earliest examples of such integration can be found in (Janssen & Rietveld, 1990) where mechanisms were developed to feed the spatial data from Arc/Info system to a specially developed multicriteria analysis method called IFINITE to address agricultural land use decisions. Carver (1991) integrated three different multicriteria procedures in Arc/Info. However, the most significant contribution in integrating GIS and MCDM techniques was been done by Eastman et al. (1993) and their contribution resulted to the introduction of an addition of analytical decision support tool to version 4.1 of IDRISI. Introduction of spatial multicriteria evaluation module in ILWIS also been reported recently (Sharifi et al., 2003a).

The way these two components are integrated depends on the philosophy behind the design strategy, the types of decision problems, and the MCDM models incorporated into the system. Despite these differences, the basic structure such integrated tools are generally composed of main three elements: a GIS database, multicriteria models and a user interface (Malczewski, 1999). To develop the framework for spatial decision support system these components need to be intergraded to provide a user-friendly environment for each stage associated with problem solving activities.
The fundamental issue in deciding the data model for the integrated system is the compatibility of the data constructs between the GIS model and the MCDM modelling system. It has been observed that

the raster based GIS and relational DBMS are more appropriate for multiattribute decision modelling. The grid based spatial construct provides a convenient data model for reprinting the attribute data in tabular format (i.e. in the form of decision matrix or evaluation matrix) that can serve as data input for multiattribute modelling.

For the decision makers, the user interface plays a very significant role. It can be considered as a surface through which data and information are passes back and forth between the user and system. There are several possible interface modes that can be used to design the interface between GIS and MCDM techniques. The graphical user interface (GUI) provided by most of the GIS software packages can be used and extended to provide a very user friendly and interactive mechanism for computer-user interaction. Advanced visualisation techniques in multicriteria decision analysis also can play a very important role for computer-user interaction (Malczewski, 1997).

2.9.1. Coupling GIS and MCDM systems

Coupling is a measure of the degree to which functions of software can be controlled directly from another. It refers to the physical and logical connection between the software packages in the in the system. In general two coupling strategy can be distinguished:

Loose coupling approach facilitates the integration of GIS and MCDM techniques using file exchange mechanism. This approach combines the capabilities of separate models for GIS functions and MCDM by transferring files (Jankowski, 1995). This integration approach significantly contributes to the embedding of multicriteria decision analysis methods within a spatial information system and also to fuse the capabilities available in the individual systems to provide a desired level of usability. In this approach data interchange standards plays important role in software and hardware integration and in user interface design. Examples of loosely coupling strategy for integration GIS and MCDM techniques are used widely (Janssen & Rietveld, 1990; Jankowski et al., 1994; Jankowski, 1995; Zhao et al., 2001). For instance, Jankowski (1995) developed an integration approach for land suitability analysis having three components: GIS module, MCDA module and file exchange module. PC-ARC/INFO provides the GIS capabilities. The MCDA module is a collection of four stand-alone computer programmes implementing different MCDM techniques. The file exchange module is comprised of two programmes: one that generates the decision table and another that changes its format to input file format of the MCDA programmes. An input file containing the decision table can then be opened from the selected MCDA programme. The decision matrix is generated by an interactive programme written in SML (Simple Macro Language of PC-ARC/INFO). In another approach Zhao et al. (2001) demonstrated a methodology to integrate a GIS package (Arc View 3.2) and a MCDA package (CDP-Criterium decision Plus3.0) by means of a bi-directional data transfer based on Dynamic Data Exchange (DDE) protocol. The Arc View acts as visualization engine and CDP acts as data analysis engine. This approach is widely used by several researchers considering the following advantages:

Both MCDA and GIS are well-established tools but essentially separate field of research. The state-of art software are available that may be used directly when loosely coupled and this integration technique is the basis of most approaches that involves the integration of systems (Parks, 1993).

Most of the GIS and MCDA programmes are typically proprietary systems and developed and maintained externally with limited opportunities for local modifications. At a technical level MCDA programmes are of comparable size and complexity to a GIS, consequently re-implementation of a MCDA programme within GIS would be a daunting and costly task (Zhao et al., 2001) It is comparatively easier to customize GIS software or loosely integrate them with other software programme for specific GIS based application. The integration typically involves deigning of specialised linkage components to facilitate coupling. However, in this context identifying the type of linkage component needed is one of the core issues of the system integration problem.

Another approach for coupling the two systems is tight or close integration strategy is based on a single data or model manager and a common user interface. The tight coupling strategy involves calling up MCDM analysis routines from within GIS software (Jankowski, 1995). It allows the two modules to run simultaneously and share a common database. The developments of the spatial data transfer standards (SDTS) and increasing availability of open GIS toolboxes facilitates the tightly coupling strategy. However this approach requires a high level of knowledge of the GIS in question and considerable programming skills. “Macro language” facilities available in a proprietary GIS are used to couple with MCDM models. To provide a full range of decision support functionalities the GIS system need to be customised. Carver (1991) provides an early example of such an approach. Examples of more extensive integration based on this approach can be found in the IDRISI/ Decision analysis module and also in ILWIS. These are the two full features GIS systems provide the wide range of Multicriteria spatial decisions making capabilities.
The advantage of this approach is that the decision problem can be modelled using generic tools on a single integration database. However they require high level of computational knowledge and

3. Chapter III: Integrated methodology for Multicriteria Decision Making

3.1. Introduction

Technological innovations and advancement in the field of RS and GIS contributed significantly in mapping, analysis and monitoring of the processes that are taking place on the surface of earth. Such technologies provide information of varying spatial and temporal scales and assists in planning and decision-making. However their potentials could not be explored fully yet due to numerous complexities that is associated with the human-nature interactions. In the process of planning and decision making human judgements need to supplement the information, which is otherwise valueless in itself. Land resource planning is considered as process of decision making on land allocation and on underlying management options based on consensus that involves informed participation of land users/decision makers at various levels and involves specialised resource allocation problem. The main challenges for the planners and decision makes are to formulate complex, spatially and temporally interdependent patterns of uses that can achieve multiple, non-commensurable and frequently conflicting objectives and goals. Decisions about land resource planning are rooted in the physical and biological sciences, but they are driven significantly by human behaviour (Mohamed et. al., 2000) and it has been widely recognised that the most reliable way to modify human behaviour for effective resource management is to bring key decision makers through a process of "discovery" (Grant & Thompson 1997).

In this chapter, we will analyse the process of land resource planning and decision-making for sustainable land resource allocation among competing land use types. In the process we will investigate how conventional multicriteria decision-making techniques can be integrated in a GIS environment to address spatial planning and decision-making problems. In our approach both multicriteria and multiobjective decision analysis is addressed to the land resource problem. Multicriteria analysis is applied to investigate land suitability for identified uses and multiobjective analysis is applied for conflict resolution and allocation. For multicriteria land suitability evaluation we investigated two different approaches: spatial AHP method and spatial compromise method. Where as multiobjective conflict resolution is achieved through multivariate numerical classification method.

3.2. Difining the decision problem

Land resource planning, as defined by Dent (1988), 'should provide capability to help decision makers to decide how to use land: by systematic evaluation of land, alternative pattern of land use, choosing the best of which meets specific goals and drawing of policies and programs for the use of land'. Such a task can be decomposed in two distinct parts. The first part is to investigate the potential land use systems, i.e. the land utilisation type that can be adopted for a particular area and evaluation of the suitability of the land for such uses. The second part is to find the relative competitions and conflicts among the potential land uses in a systematic manner and to develop strategies for allocation of land uses. The allocations need to done in such a manner that it minimise conflicts among the alternative land use systems. As discussed in chapter2, land resource planning is a complex and multidimensional decision making task. The major complexities are contributed from the following facts: (a) Involvement of quantitative and qualitative evaluation factors in the decision-making b) Require integration of data and information from wide spectrum of disciplines c) Involves expert's knowledge d) Needs inputs from different stakeholders and assessment from different experts e) Need for identification of conflicts and methodology to resolve them.

The problem of land resource planning is analysed for adoption of new methods to propose a methodology that can make use of available technology and can handle the problems associated in efficient and effective manner to draw up the possibilities for sustainable land resource planning for multipurpose land utilisation strategy. Any imbalance or conflict in the land use has serious impact on the potential site, so it is assumed that the less conflict between land-use systems, the more sustainable is the land use for a certain piece of land. This statement leads us to at least two questions: (1) how can land use systems be described and defined generally and site specifically, and (2) how can the interactions (conflicts) between the land use systems be evaluated. It is widely acceptable that utilisation of land is multifunctional and actual land use allocation is an achievement of a decision. Such a decision making process broadly incorporates the following two activities:

1. Identification of potential alternative land use types and assessing the land suitability for such uses.
2. Identifying conflicts/competition among the potential land use types and designing measures to resolve such conflicts in the allocation process.

In this research, the processes involved these two above mentioned activities were further divided into following four phases to develop and evaluate an integrated methodology for multicriteria decision making (Fig: 3.1):

Phase I: Identifying the alternative land uses

Phase II: Multicriteria suitability assessment of land for the identified uses

Phase III: Multiobjective conflict resolution and allocation

Phase IV: System development for integration of MCDA & GIS tools

Fig: 3.1 represents the conceptual model adopted for the study. This deals with the identification of alternative land uses based on physical parameters of land suitability and socio-economic need and preferences. The second phase deals with multicriteria land suitability evaluation. The suitability of the land is evaluated based on biophysical characteristics of the land and socio-economic factors. MCDM techniques are applied to incorporate decision maker's judgement and preferences to evaluate the suitability of land for the specified uses. In both of these phases expert's knowledge is extensively used to identify the alternative uses and to determine the factors for suitability evaluation. Once the suitability for the different land uses are evaluated, the third phase deals with identifying the conflicting areas where land suitable for more than one land uses and there is competition among the uses for their spatial allocation. To resolve such conflicts and to achieve sustainable allocation of the alternative uses multiobjective decision analysis is applied. This approach facilitates to identify homogeneous regions for the intended uses and also helps to maintain spatial contiguity. The fourth phase deals with the integration of the MCDM techniques applied for this study in a GIS environment to provide a basic framework for spatial decision support system. In the subsequent sections we will address these issues one by one and will see how GIS and MCDM techniques plays a significant role in the entire process.

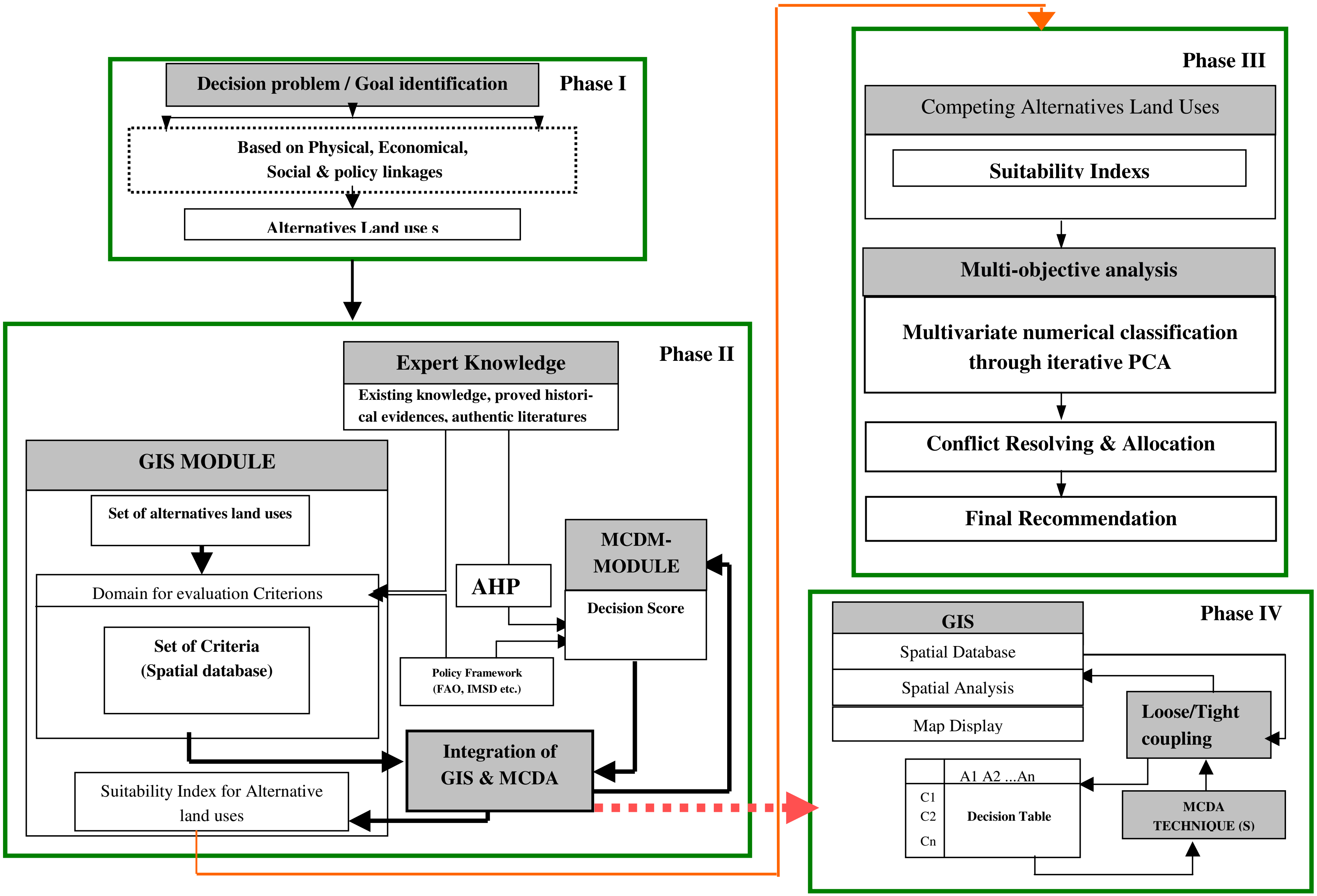


Figure 3.1:Conceptual model for the land resource planning

3.3. Identifying alternative land uses

Land resource-planning aims at allocation of land to various categories of uses according to predetermined criteria. Success of such a process requires in depth analysis of the existing systems and an understanding of development potentials in order to identify the uses for the natural resource that will not prejudice future development (Senes et. al. 1998). Hence at this phase we focused on identifying the potential alternative land use systems that can achieve the desired social and economic goals and at the same time also match the biophysical characteristics of the land. In planning and decision making terminology this is analogous to intelligence phase of decision-making framework (Fig: 2.2). Identification of problems with present land utilization pattern and to explore the potential opportunities for future development, which is environmentally sustainable and economically viable, needs systematic study of the situation.

This requires knowledge, experience and expertise of several domains and information from various sources. The first phase of the methodology deals with developing a knowledge base in context of the particular decision problem at hand. Knowledge acquisition have been accomplished through discussions with expects of related fields of study, surveying of authenticated literatures, analysis of historical data. Need and priorities of the local people and of indigenous knowledge is also taken into consideration while formulating the alternative land use scenarios. This was achieved through informal meetings and participatory appraisal. The information acquired through these processes provides the knowledgebase on the decision domain and is used in successive stages of analysis and evaluation. A comprehensive survey of the case study area was taken up to analyse the biophysical and socio-economic situation (Fig: 3.2) and the findings were discussed with a panel of experts from the domain of agriculture, soil science and forestry.

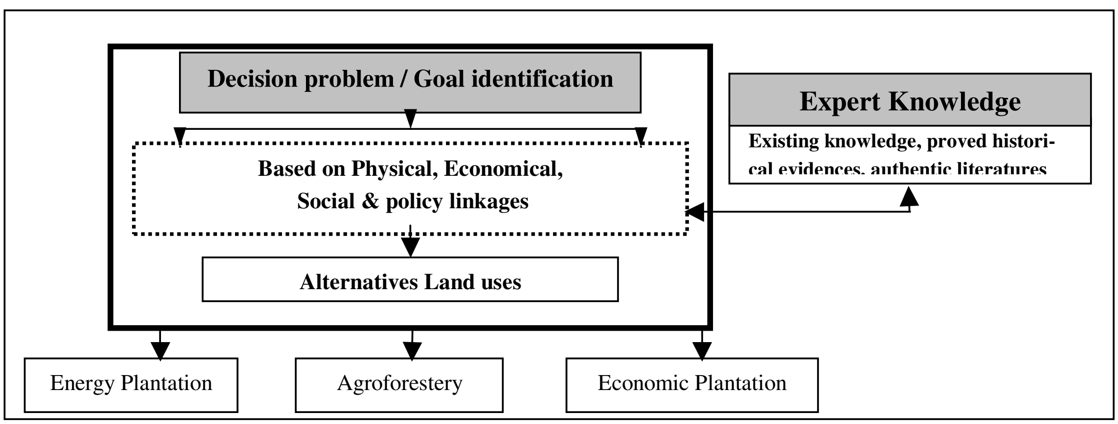


Figure 3.2:Identification of alternative land uses

The silent features of case study area can be characterized as:

i. The area is predominantly drought prone with erratic and low rainfall
ii. The land is degraded to a great extent with low soil depth and poor fertility
iii. Single cropping is predominant, making agricultural production vulnerable
iv. People are heavily dependent on forest resources for the fodder and fuel wood requirements, leading to indiscriminate felling of forests.
v. Degradation of forest area in the uphill land causing serious problem of soil erosion

The area is also very poor in terms of other resources like mineral resources and infrastructure development. Hence any future developmental activity need to be achieved through land based activity. Analysis of the present situation and future developmental opportunities by a group of experts brings us to the consensus that any future land developmental activity should focus the following objectives:

i. Supplementing agricultural production to ensure food security
ii. Alternative sources for fuel and fodder to reduce the pressure on natural forests
iii. Soil and water conservation
iv. Measures of sustained income generation
v. Reclamation of degraded lands

Objectives are the goals or desired state of the system that need to be achieved through the decision making process. They define the purpose and perspective of the process and play an important role in defining how the decision is structured. Purpose defines the number of alternatives to be considered and the nature of the decision set whereas perspective determines the decision rules. They answer the questions like what criteria to be chosen, how they are evaluated and how the final decision is made (Eastman et al., 1998). Objectives are concerned not only with a final selection of decision set, but also with issues of motive and social perspective and act as a guiding force in the development of specific procedure and decision rules.

Definition of alternative land use scenarios

Considering the abovementioned objectives as the driving force for the planning task at hand, the decision maker(s) enumerated a list of potential development action(s) that constitute the alternative scenarios for the decision problem. Based on the discussion with the same group of experts, local stakeholders, consultation of relevant literatures and previous works on similar situation the following alternative land use systems were identified as suitable for the case study area. Decision makers are considered as a link (translator) between the land and the stakeholders and play a very important role in translating the goals and aspiration of the stakeholders in to a scenario, for example in the present context a scenario represents a particular land use system. At this stage of the study precautions are required to come up with neutral description of the scenarios in order to minimise possible influences of the decision maker and the panel of experts need to an efficient use of all the available data, models, software and theoretical knowledge in order to help the Decision-Makers (DMs) to consider and compare available solutions or alternatives (referred by Joerin et. al. 2001 citing Dente et al. 1998).

Table 3.1: Alternative land uses and associated objectives

Alternative land use	Objectives
Agroforestry	Supplement agricultural production Soil & water conservation Sustained income generation
Economic plantation	Supplement agricultural production Employment generation
Energy plantation	Meet the demand of fuel & fodder Soil & water conservation Wasteland reclamation

The three alternative land use systems identified by the group of experts are described as follows:

Agroforestry:	is a system of land utilisation in which plantations of trees are integrated in farmlands. The main objective of this system is to diversify and sustain production from farmlands. It also plays a very important role in soil and water conservation and reclamation of degraded lands.
Economic plantation:	is a system of land utilisation that aims in production of economically valuable trees and plants. The main objectives are to produce economic benefit and supplement agricultural production, land reclamation and conservation
Energy plantation:	is a system of land utilisation where specific species of plants are cultivated for the purpose of fuel and fodder production. It aims at production of sustained energy source and reduction of pressure on natural forests.

Selection of the alternative land use systems was also guided by administrative and developmental priorities identified and formulated in the form of framework of IMSD (Integrated Mission for Sustainable Development) by Government of India. IMSD is a programme initiated by department of Space, Government of India, for generating spatial data infrastructure for district level planning and decision-making. It aims at developing action plan for land and water resource development activities.

3.4. Multicriteria suitability assessment of land for the identified uses

As discussed in the earlier sections, suitability assessment of a particular tract of land for the specified uses comprises an integral part of land resource planning. Suitability assessment can be defined as the procedure of determining the fitness of the given tract of land for a specified use. It is a strategic process directed at the evaluation of the biophysical and socio-economic characteristics of the area under consideration. These characteristics of the land or the area are defined as decision criteria in MCDM terminology. Land suitability modelling is applied to derive suitability index, which is a unitless variable describing the priority (suitability) of the land with respect to the factors that determine the suitability of that particular system of land utilisation.

Land suitability assessment, which is often designated as land suitability evaluation (LSE) is considered as a multiple criteria decision problem and need to be addressed through multiple criteria decision-making methodologies. Multicriteria characteristic of LSE pertains to the fact that, several biophysical and socio-economic criteria determine the actual suitability and acceptability of that particular land use system. This particular characteristics forces involvement of a wide domain of knowledge and expertise in this process and also needs to accommodate the social preferences and aspirations.
So at this stage we identified the potentially suitable areas for the respective land use systems and the suitability values were quantified based on aggregated performance of the relative contribution of the criterions that determine the suitability of a particular land use system.

3.4.1. Criteria Definition and database creation

It has been indicated by several researchers (Store et al., 2001) that empirical models for determining land use suitability is not appropriate to make use. This is due to the fact that, these techniques are mostly relies on statistically quantified criteria /factors by exploring the relationship between existing occurrence of specified land use and site properties. Such a methods are subjected to several limita-

tions and in many cases it has been observed that deriving the suitability factors empirically are not feasible or expensive and time consuming. To over come this problem we have taken an approach to use expert knowledge in defining the criterions used for the land suitability modelling.
Discussion with the experts from various backgrounds of physical and social sciences resulted in the identification of various physical and socio-economic attributes that need to be incorporated in the evaluation to assess the suitability of land for different system of use. These attributes were then translated into specific spatial criteria and a GIS database is created. The database includes the following layers: land use and land cover, slope, soil depth, soil texture, soil fertility, ground water depth, soil moister deficit, distribution of wasteland, village wise biomass distribution, village wise fuel wood deficiency. Generation of the database involves supervised classification of satellite imagery and visual interpretation; the socio-economic attributes were collected through survey and were converted into spatial layers in GIS environment. This database was used in the subsequent sate to derive the suitability index for the respective land use systems. Database creation was also supplemented by ground survey and consultation with the experts who are familiar with the area under consideration.
The next step is to classify the criterion/decision factors into deterministic and non-deterministic category according to their exclusive character. Deterministic criterions are Boolean type of variables, which are used like geographical constraints to eliminate areas from further consideration on the basis of certain attribute values (Store et al., 2001). Non-deterministic criterions are impact factors that act as continuous modifiers in land suitability assessment. Suitability of the land is evaluated based on the relative importance of these non-deterministic criterions

3.4.2. Multicriteria suitability assessment

The objective of the multicriteria suitability analysis is to determine the suitability of the land based on multiple criterions or factors that regulate or determine the suitability of land for the specified use. In conventional GIS analysis also multicriteria techniques can be performed, however they do not provide any mechanism to incorporate decision maker's judgement and priorities in the evaluation process.
The approach followed in this research integrates GIS based spatial analysis techniques and MCDM techniques for multicriteria evaluation. MCDM techniques are used to incorporate differential importance of the different decision criterions and the attributes associated with them, in the evaluation process. This also provides a mechanism to use expert knowledge and decision maker's judgements in the GIS based suitability analysis.
As discusses earlier in the research we have used raster data set considering it's wider mathematical capabilities. In a raster-based suitability analysis set every individual pixel is considered as a decision alternative and suitability score for every pixels need to be computed. In this process integration of GIS with conventional multicriteria decision making techniques play very significant role. The suitability score of all the individual pixels can be computed by several MCDM techniques. In this research we investigated two different approaches to evaluate the suitability of the individual pixels for the respective land uses. Fig: 3.3 represent the framework of the multicriteria suitability analysis. This process (Fig: 3.3) involves two distinct processes; the first process uses MCDA module to derive the relative importance or weights of the different criterions that was considered for suitability assessment and the second process uses the GIS module to perform spatial analysis and presentation of maps. In the MCDM module we have used two different approaches:

- Spatial Analytical Hierarchy Process (Spatial AHP)
- Spatial compromise programming (Spatial CP)

Two different approaches were followed to have a comparative study of the results obtained form the two different MCDM methods. It has been indicated by several researchers that choice of MCDM methodologies affects the results obtained through these processes. The results obtained from these two processes were compared to find the variations in the suitability scores obtained. This gives an insight regarding the subjectivity of the MCDM approaches and their methodological difference.

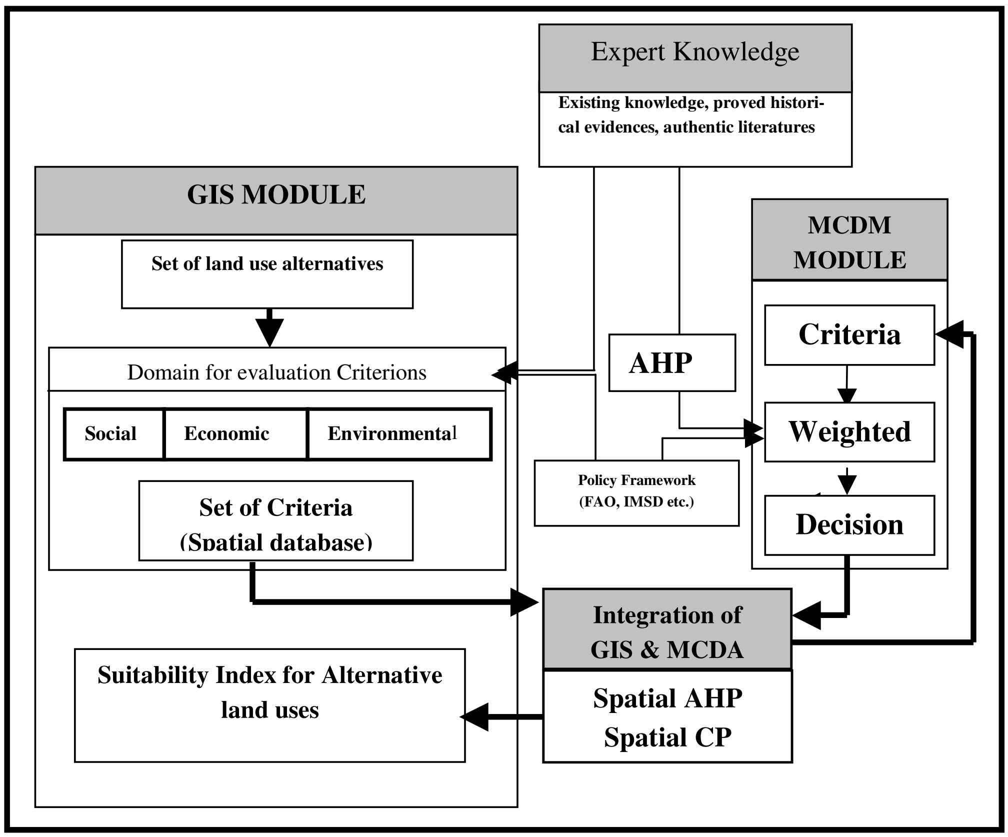


Figure 3.3:Multicriteria land suitability evaluation

3.4.3. Spatial-Analytical Hierarchy process (AHP)

Spatial-AHP is the term coined by Siddiqui et al., 1996 for the additive multicriteria decision analysis approach that integrates GIS and AHP. In this research Spatial –AHP is used to identify suitable areas for a particular land use system and to quantify the level of suitability through the utilization of knowledge based user preference and data contained in GIS maps. As we know all the criterions/decision factors are not easily quantifiable or measurable using related units, application of AHP provide us the facility to incorporate those criterions also that lacks pre-existing quantitative scale or that are otherwise not commensurable.

As discusses in the earlier chapter, AHP method is based on three principles: decomposition, comparative judgment and synthesis of priorities. In the present study the Spatial-AHP method involves the following steps:

- Identification of criterions/decision factors } Decomposition
- Structuring the criterions/decision factors in hierarchy
- Judging the relative importance of the criterions of the decision hierarchy - comparative Judgment
- Aggregating the measures to calculate suitability index - …………………...Synthesis

In this section we will discuss the methodology for evaluating suitability for the identified land uses. Here we have given the details involved in this method for a particular land use (i.e. energy plantation). Similar approach has been applied to derive the suitability of the other two land uses also and the description of them can be seen in Appendix A.

Developing AHP hierarchy

The first step in the AHP procedure is to decompose the decision problem into a hierarchy that consist the most important element (i.e. the criterions/ decision factors) of the decision problem. At this stage based on the principles of decomposition the identified objectives, factors and sub factors that determines suitability of the land use type is are arranged in to a hierarchy. A basic form of the hierarchical model of a decision problem is a pyramid with the ultimate goal of the decision at the heights level and descends towards lower levels listing the decision factors; sub factors until a level of attributes is reached.

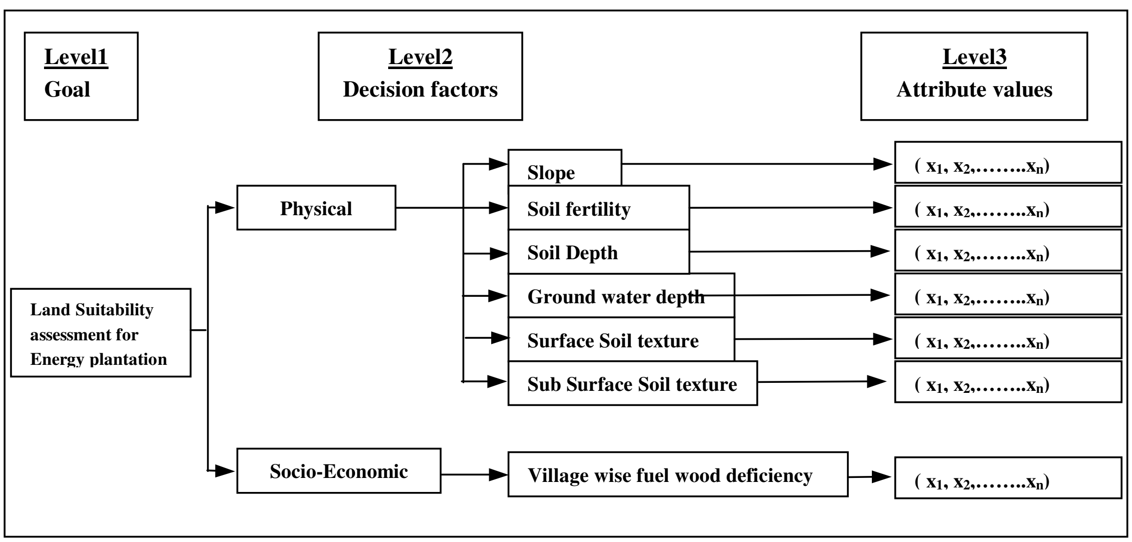


Figure 3.4:Decision hierarchy of land suitability assessment for energy plantation

Fig: 3.4 show the decision hierarchy for the land suitability assessment for energy plantation. Structuring the hierarchy is a relatively subjective activity and depends on decision maker's experience and knowledge about the decision problem. A hierarchy should focus on those factors that that are most important to the decision maker and that will help him/her make the required choice. In the GIS database the attributes are represented as map layers and contains attribute value for each pixel (in raster database). The Hierarchical structure for the other land use alternatives is presented in the Appendix A

Deriving relative impotence based on pairwise comparison

To find out the suitability of the land for a particular use, two levels of weighting have been performed: (1) weighting of the attributes associated with each factor (attribute values of the map layers) and (2) weighting of criterions/ decision factors (map layers) layers .The first level is to determine the importance or contribution of the attribute values associate with the decision factors and the second level of weighting determines the relative importance or weight of the decision factors or criterions itself.

AHP uses pairwise comparisons to derive the relative importance or weight of the criterions or decision factors.. It involves three steps:

1. Development of a comparison matrix at each level of the hierarchy, beginning at the top
2. Computation of relative importance or weights for each element in the hierarchy
3. Estimation of consistency ration

Comparison matrix (Table: 3.2) is developed based on the 1 to 9 scale of linguistic measures of preference developed by Satty (See Table: 2.1). Table: 3.2 show the pairwise comparison matrix for the attributes associated with slope factor. Once the comparison matrix is prepared weight assigned to each hierarchy element is determined by normalising the eigenvector of the comparison matrix. Eigenvector values are estimated by multiplying all the elements in a row and taking the N^{th} root of the product, where N is the number of row elements. For example, for the first row in Table 3.2 the eigenvector value is $(1*2*3*5*9)^{1/5}$ or 3.0639. Relative importance of the matrix elements is derived through normalisation of the eigenvector values. Normalisation of the eigenvector is accomplished by dividing each eigenvector by the sum of the eigenvector elements. For the first row in Table 3.2, the relative impotence or weight is {3.0639/ (3.0639 +2.7508+1+0.4911+0.2416)}, or 0.4059. It is apparent from the weight column of Table 3.2, the relative importance or weight is higher for a lower amount of slope values, indicating that it is preferred.

Table 3.2:Calculation of weights for slope map

Slope Map							
	< 1%	1-5%	5-15%	15-25%	25-35%	Estimated Eigen Element	**Weight**
< 1%	1	2	3	5	9	3.0639	**0.4059**
1-5%	1/2	1	5	7	9	2.7508	**0.3645**
5-15%	1/3	1/5	1	3	5	1	**0.1325**
15-25%	1/5	1/7	1/3	1	3	0.4911	**0.0651**
25-35%	1/9	1/9	1/5	1/3	1	0.2416	**0.0320**

In the same way the relative importance or weight for the attributes associated with all the criterions are calculated. Table: 3.3 shows the relative importance of the attributes for the criterions considered for suitability assessment for energy plantation. In the same way attributes associated with the criterions that are associated with other land use alternatives (i.e. Agroforestry and Economic plantation is also derived). The listing of the weights for the attributes for the criterions associate with the criterions for these land uses can be seen in Appendix A.

Table 3.3:Relative weights of the attributes associated with the criterions

Criteria: Slope		Criteria: Ground water depth		Criteria: Soil depth	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
<1%	0.0651	5-25meter	0.3112	50-85cm	0.0393
1-5%	0.3645	15-35meter	0.4830	65-150cm	0.1259
5-15%	0.4059	20-35meter	0.1185	85-165cm	0.5650
15-25%	0.1325	20-45meter	0.0623	>150cm	0.2696
25-35%	0.0320	30-45meter	0.0250		
Criteria: Surface soil Structure		Criteria: Sub surface soil Structure		Criteria: Soil fertility	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
Loam sand to sandy loam	0.0974	Sandy loam	0.0253	High	0.4296
Sandy loam	0.0298	Sandy loam to loam	0.0590	Medium to high	0.3431
Loam to sandy clay loam	0.0484	Sandy loam to sandy clay loam	0.0405	Medium	0.1919
Sandy loam to silt loam	0.2766	Loam to silt loam	0.1497	Low	0.0355
Sandy loam, silt loam and loam	0.2303	Loam to clay loam	0.0959		
Sandy loam to sandy clay loam	0.3174	Clay loam	0.2274		
		Sandy clay loam to clay loam	0.4020		
Criteria: Village wise Fuel wood Deficiency					
Attribute classes	Weights				
Low	0.5650				
Medium	0.2696				
High	0.1259				
Very high	0.0393				

The same process of pairwise comparison is also applied to derive the relative importance or weight of the criterions. In this case the criterions are compared in pairs and the comparison matrix is developed. Once we derive the comparison matrix the same approach applied for the calculation of weights for the attributes are applied to derive the relative weights for the criterions. Table: 3.4 show the relative importance of the criterions used to evaluate land use suitability for energy plantation.

Table 3.4: Relative weights of the criterions for suitability evaluation of Energy plantation

Land Use	Slope	Ground water depth	Soil Depth	Surface soil texture	Sub surface soil texture	Soil fertility	Fuel wood deficiency
Energy Plantation	0.1023	0.2567	0.0741	0.1019	0.1650	0.1630	0.1414

Consistency ration was estimated to find out the bias and inconsistency of the decision maker and the required improvements were applied. Consistency ratio was calculated at every stage of weight estimation through the following operations (Table: 3.5):

(a) Determination of weighted sum vector by multiplying the weight for the first factor (1% slope) times the first column of the original pairwise comparison matrix (Table: 3.2), then multiplying the second weight times second column and so on. And finally summing the values over the rows and (b) determining the consistency vector by dividing the weighted sun vector by the criterion weights determined previously (see Table 3.2).

Table 3.5 Determining the consistency ratio

Criterion	Step I	Step II
< 1%	{(0.4059*1)+(0.3645*2)+(0.1325*3)+(0.0651*5)+(0.0320*9)}	2.1459/0.4059= 5.2867
1-5%	{(0.4059*0.5)+(0.3645*1)+(0.1325*5)+(0.0651*7)+(0.0320*9)}	1.9736/0.3645= 5.4145
5-15%	{(0.4059*0.33)+(0.3645*0.2)+(0.1325*1)+(0.0651*3)+(0.0320*5)}	0.6946/0.1325=5.2426
15-25%	{(0.4059*0.2)+(0.3645*0.14)+(0.1325*0.33)+(0.0651*1)+(0.0320*3)}	0.7305/0.0651=5.1771
25-35%	{(0.4059*0.11)+(0.3645*0.11)+(0.1325*0.2)+(0.0651*0.33)+(0.0320*1)}	0.1647/0.0320=5.1477

Once we calculated the consistency vector (Table: 3.5), we can calculate the lambda (λ), i.e. the average value of the consistency vector.

$$\lambda = (5.2867+5.4145+5.2426+5.1771+501477)/5 = 5.2537$$

The calculation of CI (consistency Index) is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrices, and λ=n if the pairwise comparison matrix is a consistent matrix. Accordingly (λ-n) can be considered as a measure of the degree of inconsistency and can be normalised as:

$$CI = (\lambda\text{-}n)/(n\text{-}1)= (5.2537\text{-}5)/(5\text{-}1)= 0.6343$$

CI provides a measure of departure from consistency, and then we calculate the Consistency ration (CR) as follows:

$$CR = CI/RI= (6343/1.12)= 0.055$$

Where, RI is the random index, the consistency index of randomly generated pairwise comparison matrix. A value of CR< 0.10, indicates a reasonable of consistency in the pairwise comparisons, as we the results indicate in our case too.

Aggregating the relative importance to get suitability index

The final step involved in AHP is to aggregate (Equation: 3.1) the relative weights obtained at each level of the hierarchy to calculate the suitability index. This is calculated using the following formula:

$$SI = \sum_{i=1}^{N2} \{ RW_i^2 * RW_{ij}^3) \} \text{ ....(Equation 3.1)}$$

Where, SI = suitability index; N2 = the number of level 2 decision factors; RW_i^2 = relative weight of i^th^ decision factor at level 2, RW_{ij}^3 = the relative weight of level 3 attribute j of level 2 decision factor i. The composite weight represents suitability score of individual pixel (in the raster database) with respect to the over particular land use system under consideration.

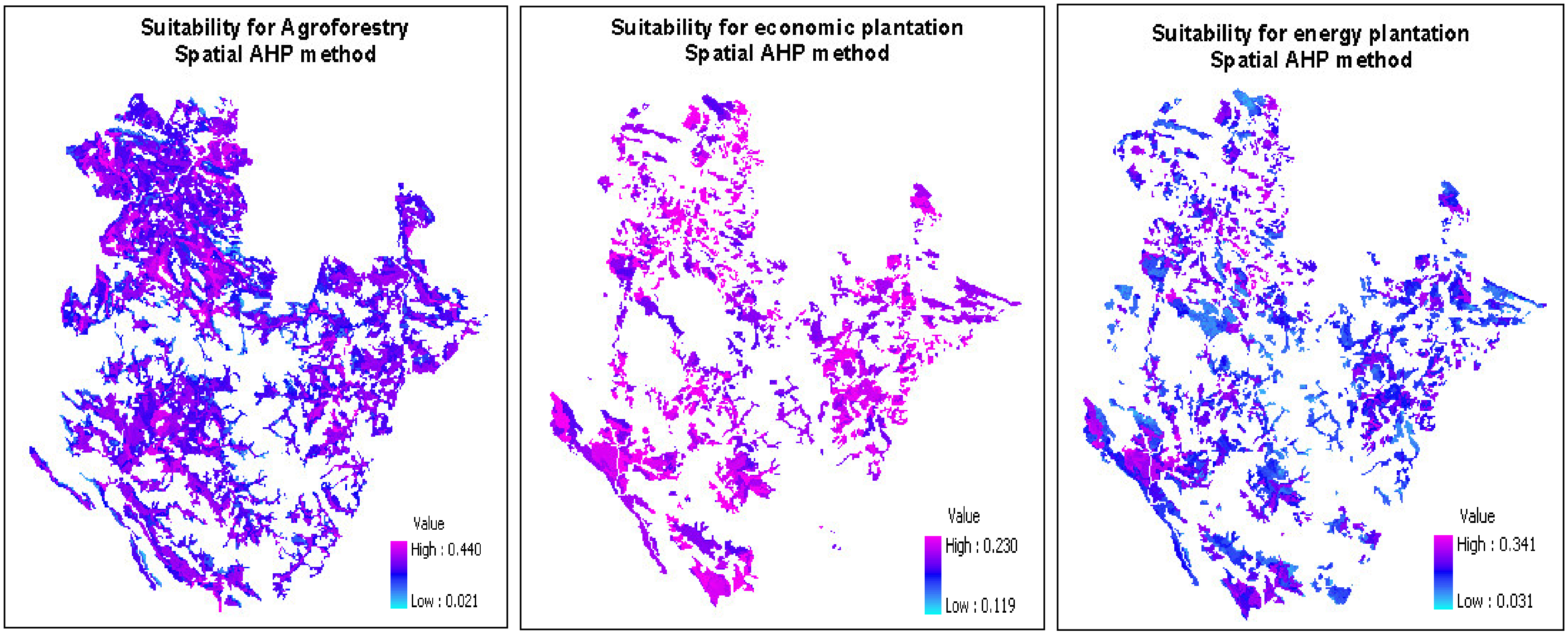
Area constraint setting:

Constraints represented in terms of administrative or legal regulations and physical impracticality are applied to eliminate the areas that are not feasible or suitable for intended activities, Ideally constraints are applied at the beginning of the suitability study to exclude the sites from further consideration. Legal restrictions like notified forested areas cannot be considered for any developmental activities and physical impracticality like areas with surface water were excluded from the suitability evaluation through multicriteria evaluation.

In this way through the application of Spatial AHP, suitability of land for energy plantation is determined. At the end of this process we come up with a suitability map that represents the potential areas that are suitable for that particular land use (Fig: 3.5). The values associated with individual pixels represents the level of suitability of that particular pixel (i.e. geographical area) for that particular land use.

In the same way this process is applied to evaluate land suitability for all the identified alternative land uses. This process derives three suitability maps (Agroforestry, Economic plantation, Energy plantation) for the respective land uses (Fig: 3.5), in which every pixel is having a suitability value for the respective land uses. These suitability maps constitute the input data source for conflict analysis and were used later on for multiobjective analysis for conflict resolution and to determiner potential pattern for the allocation of the alternative land uses. Prior to performing the multiobjective conflict analysis, the suitability maps for the respective land uses were normalised to a 1(minimum) to 100(maximum) suitability scale. This is important to avoid the range effect and help us to analyse and locate the conflicting regions where multiple land use systems are competing for the same space. Identification of conflicting areas was performs using the overlay operation in GIS.

As we have already mentioned, in this research we have selected two different MCDM approach to evaluate the suitability of the land for the specified uses. The next step involves determining land use suitability for the alternative land uses using spatial compromise programming (spatial CP). We will be comparing the results obtained by these two approaches in the subsequent sections.



(a) **(b)** **(c)**

Figure 3.5: Suitability maps for alternative land uses by Spatial AHP method

(a) Suitability for Agroforestry
(b) Suitability for economic plantation
(c) Suitability for energy plantation

3.4.4. Spatial Compromise Programming:

Spatial compromise programming is based on the concept of displaced ideal solution. Like spatial AHP method this approach also use decision makers preferences and a set of criteria to evaluate the suitability of the land for a particular land use. Using this technique each alternative (i.e. the individual pixels in the raster database) is evaluated with reference to the ideal solution by some measure of distance. The ideal solution is the one, which provides the most favourable or preferred value for the each of the criteria considered in the analysis (i.e. the land suitability value derived considering the best attribute values for the respective criterions considered for the suitability evaluation of any particular land use system). The distance from the ideal solution is for each alternative (each pixel in this case) is measured by what is referred as the distance metric. This value, which is calculated for each pixel, is a function of the criteria value (i.e. relative importance or weight assigned to the attributes for different criterions that need to be considered for the land suitability evaluation for a particular land use system) them selves, the relative importance of various criteria to the decision makers and the importance of the maximal deviation from the ideal solution.

As discusses in the previous chapter (Equation: 2.2), in a raster GIS dataset, the set of feasible alternatives to be evaluated (i.e. the set of all pixels in a given GIS database) can be represented as:

$$x^k = (x_1^k, x_2^k, \dots\dots\dots x_i^k); \qquad i = 1,2,\dots\dots\dots\dots, \mathrm{I}; \; \forall x_i^k \in \mathrm{X}$$

Where individual x_i^k designate the score of an attribute (map layer) *i* attained by alternative *k*, where $i = 1,2\dots\dots, \mathrm{I}$; $k = 1,2,\dots\dots,\mathrm{K}$.

Therefore x^k is a vector of K numbers, assigned to each alternative (pixel) synthesising all available information about that alternative in terms of possible incommensurable, quantitative and qualitative criteria that constitute the input dataset for the suitability evaluation for a particular land use. This vector represents all currently attained levels of the $\boldsymbol{i}^{\text{th}}$ attribute (e.g. all slope classes in a map layer of that theme), Among these values or levels, there is at least one ideal value that is preferred to all others (e.g. up to 5 percent slope, or gently sloping terrain is most preferred for Agroforestry activities) and the concept generalizes to the multiple criteria alternatives as the set of all individual ideal levels:

$$x^* = (x_1^*, \dots\dots\dots\dots\dots, x_{\mathrm{I}}^*)$$

The vector x^* represents the ideal point, a usually unfeasible alternative, characterized by the best attainable score on every criterion. Using compromise programming all the pixels in the dataset evaluated for their suitability for a particular land use system based on their multidimensional distance of the ideal point using the following formula:

$$d_p = [\sum_{i=1}^{\mathrm{I}} \beta_i^p (x_i^* - x_i^k)^p]^{1/p}, \; \beta_i^p > 0 \text{ and } \sum \beta_i = 1 \dots\dots\dots\dots\dots \textbf{Equation 3.2}$$

Here,

β_i is the relative importance or weights associated with the criterions (criterions /decision factors that determine the suitability of land for a particular land use systems), it reflects the decision makers preferences concerning the relative importance of various criteria. The parameter '*p*' reflects the maximal deviation from the ideal point. It effects the relative contribution of individual deviation from the ideal point.

This approach is applied in this research to evaluate the suitability of all the three different land use types. As mentioned earlier our objective is to compare the results obtained by spatial AHP method and spatial CP method, we used the same set of weights as derived for the spatial AHP method. For this purpose instead of the natural scale of measurement of the attributes values we used the scale of relative importance of the attribute values associated with the criterions as derived in the process of spatial AHP. Evaluation of land suitability for the specified uses through this approach involves the following steps:

- Identifying the best attribute (i.e. the ideal point) associated with the respective criterions (i.e. identifying the ideal point for each decision criterion) based on the judgement experts and decision makers (as mentioned above instead of natural scale of measurement for the attributes we used their relative impotence derived through pairwise comparison of the attributes).
- Deriving the distance maps for the criterions with reference to the ideal point. For this purpose the criteria maps that were derived through weighting their associated attributes were normalised into [0,1] interval. This was achieved by transforming the weights as per the transformation function suggested by Kamenetzky, 1982. This transformation is required to convert the weights in to a common scale. Such a transformation simplifies the computation of various distance matrices as the parameter, $(x_i^* - x_i^k)$ in the Equation: 3.2 becomes $(1 - x_i^k)$. Here, 1represents the weight associated with the best attribute for that particular criterion and x_i^k represents the weights of other attributes for which the distance matrix is calculated.
- The weight factor β_i is derived through pairwise comparisons of the criterions considered for the suitability evaluation of the particular land use type.

Once we derived the required parameters we used the Equation: 3.1 to derive the suitability maps for the identified land uses. We have considered three different value of P (1,2,10) to find the effects of the relative contribution of individual deviation from the ideal point. Following this approach we derived the suitability maps for all the three land uses.

3.4.5. Comparison of the results obtained from spatial AHP and Spatial CP

For the purpose of comparing the results obtained from these two different MCDM approaches, we have considered one particular land use type (Agroforestry) for demonstration. The variation in the results obtained can be seen in Fig: 3.6 and Fig: 3.7. The results of suitability analysis derived through different value of P (1,2,10) in spatial CP method yields clearly distinct maps, with different range of distance to the ideal suitability score. The variation in range of the suitability scores results from different distance matrices and invalidates comparison among these maps. For the purpose of comparison we converted each map in to five-land suitability classes defined at ordinal levels (Fig: 3.6). This improves the effect of different data ranges and permits comparisons between the maps. To assist the visual comparisons we also calculated the area covered under each of the five suitability classes (Fig: 3.7).

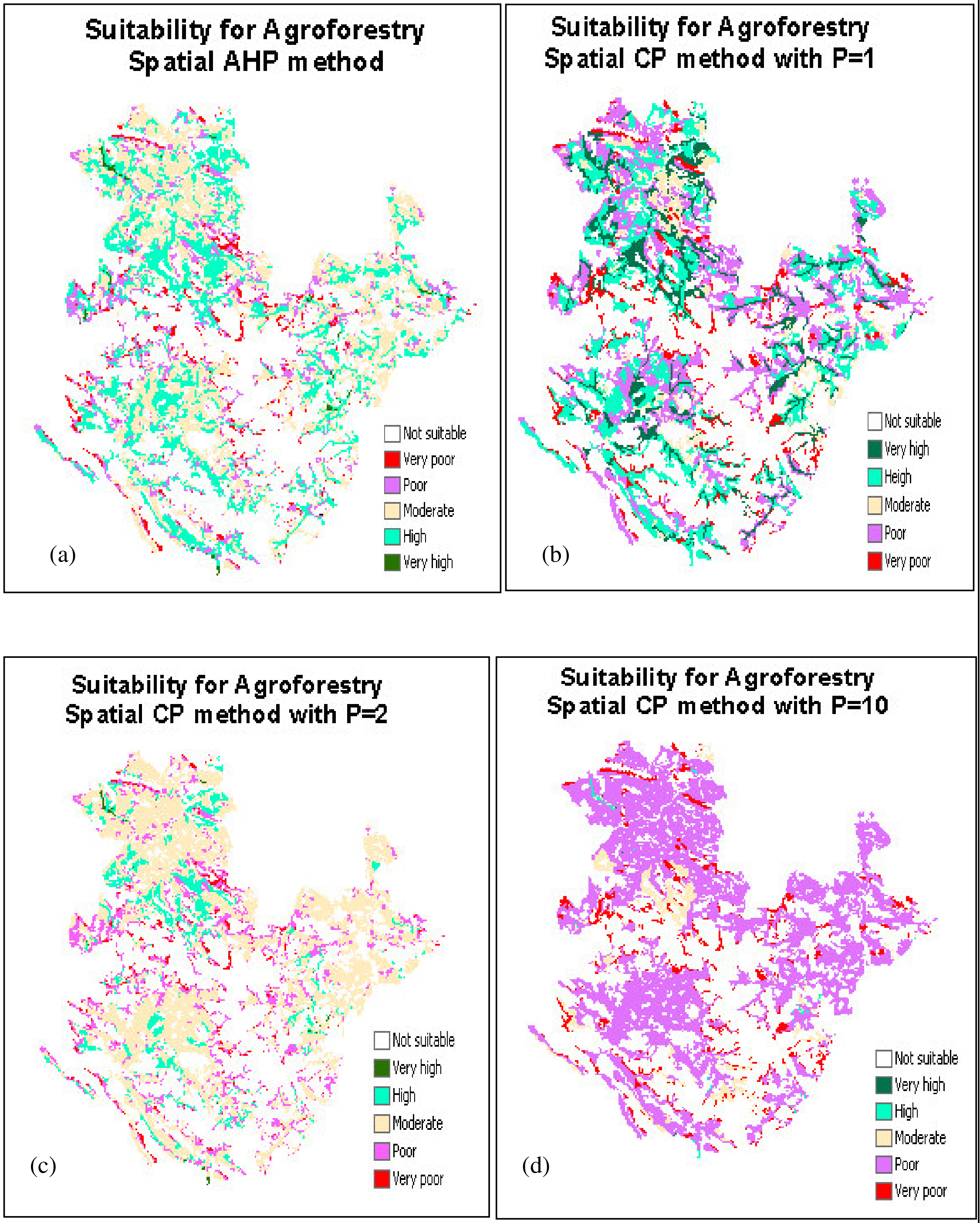
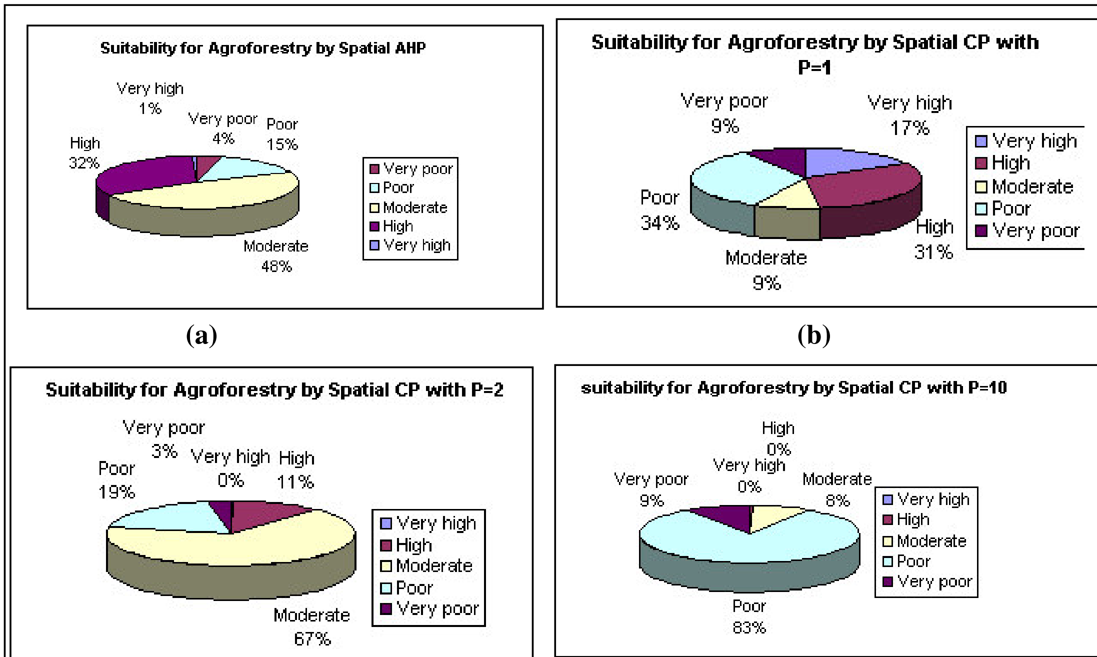


Figure 3.6: Comparisons in suitability derived from Spatial AHP & Spatial CP method

(a) Suitable areas identified for Agroforestry by Spatial AHP method
(b) Suitable areas identified for Agroforestry by Spatial CP method, with P=1
(c) Suitable areas identified for Agroforestry by Spatial CP method, with P=2
(d) Suitable areas identified for Agroforestry by Spatial CP method, with P=10



(a) (b) (c) (d)

Figure 3.7: Variation in derived suitability by different method

(a) Suitable areas identified for Agroforestry by Spatial AHP method
(b) Suitable areas identified for Agroforestry by Spatial CP method, with P=1
(c) Suitable areas identified for Agroforestry by Spatial CP method, with P=2
(d) Suitable areas identified for Agroforestry by Spatial CP method, with P=10

A simple visual comparison of the derived suitability pattern (Fig: 3.6 and Fig: 3.7) shows sharpest contrast between suitability derived using p=1 and p=10. Suitability derived using p=1 assigns a larger proportion of the area to the higher suitability classes (see Fig: 3.7-b), resulting from the compensatory nature of the underlying decision model (as we already discussed, P=1 assumes total compensation). If all the cells have poor relative importance or weights on a few criteria but good ratings on other criteria, it can still get a reasonably high score in the resulting suitability performance.

Where as, in case of suitability derived using p=10, represent non-compensatory, minimax model and rates each alternative pixel based only on the criteria showing the poorest performance. This is the reason we get a very high proportion of area under poor suitability classes (see Fig: 3.7-d). And in the case of suitability scores derived using p=2, that signifies partial compensation of the criterion performances yields a reasonable result and we can see a higher proportion of area is assigned to moderately suitable class (see Fig: 3.7-c).

Considering the comparisons of results derives from spatial AHP method and Spatial CP method, we found very high deviation when compared with the suitability obtained using p=1 and p=10 (see Fig: 3.7-a, b, d). Where as we can find similarity in the results obtained using p=2(see Fig: 3.7-a, c). From the above observation we can infer that spatial AHP incorporates some sort of partial compensation of the criterion performance.

3.5. Multiobjective conflict resolution and potential allocation:

The purpose of land resource planning is not only to evaluate the fitness of land for a particular type of use but also to assist in finding the most appropriate locations or pattern of locations for potential allocation. It has been observed that different systems of uses with incompatible activities competing for available land leads to environmental conflicts and as a result jeopardize or reduce the capacity of land for the specified uses. Considering the need for multiple uses of land and associated degrees of compatibility among them, it is important to look into the issue of land suitability assessment as a planning tool that can aid to design of a land use pattern that prevents conflicts as well as maintain spatial integrity to prevent fragmentation of land. To address this issue this research investigated a methodology based on multivariate statistical analysis to segregate areas of compete ting land uses based on their suitability scores. The process can be categorised into following steps: (1) identifying conflict among the land uses (2) devising mechanism to resolve the conflict (Fig: 3.8).

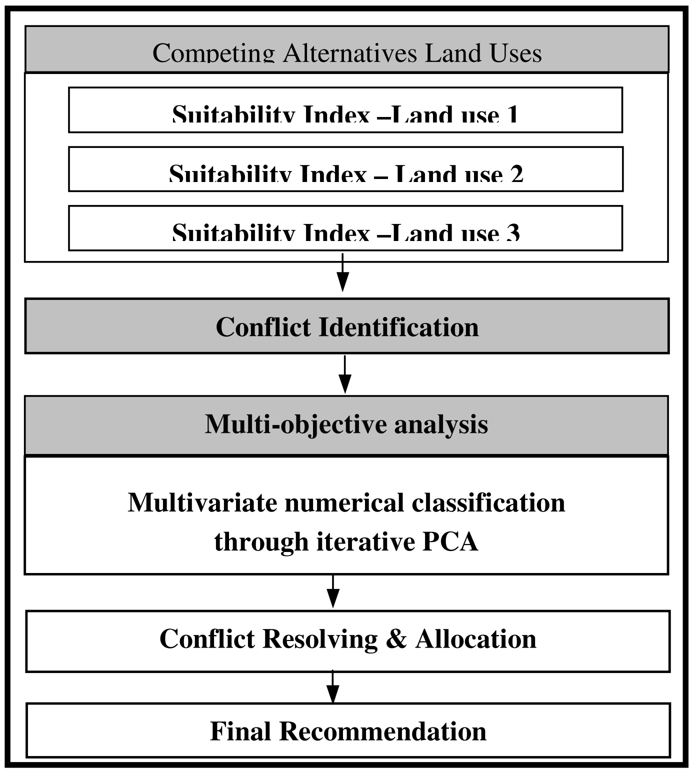


Figure 3.8:Conflict identification & resolution

3.5.1. Identification of conflicting areas

Once we evaluated the suitability of the land for different uses we can identify the areas suitable for two or more land use alternatives. Spatial analysis capabilities of GIS are used to overlay the suitability maps to find the conflict or competition among the land uses for spatial allocation. For the conflict resolution analysis we used the suitability results derived through spatial AHP method. This is due to the fact that, this particular MCDM method provided the most acceptable results in suitability evaluation of the alternative land uses and the suitability scores are also well distributed. The areas that are suitable for more than one land uses and are competing spatial allocation of the land uses can be seen in Fig: 3.9.

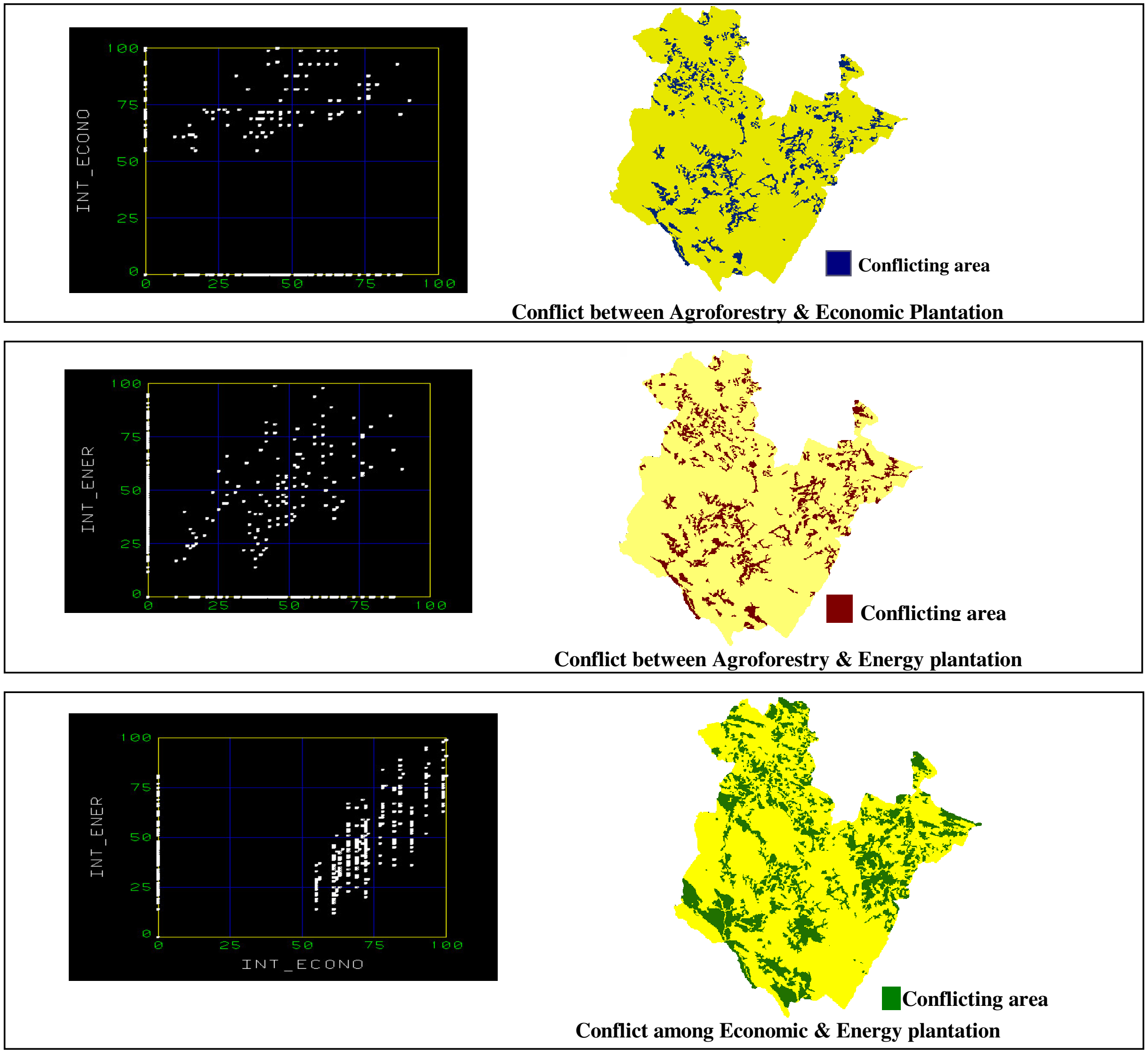


Figure 3.9: Identification of conflicting areas

The scatter diagrams in the Fig: 3.9 are plotted taking the suitability scores of two competing areas at a time this gives an idea about the magnitude of competition among the alternative land uses. From the Fig: 3.9 it can be seen that the competition is highest between Energy plantation and Economic plantation. This is due to the fact that, the objectives of both of this two land use types are complementary in nature and the factors that determines the suitability of these two land uses are common properties. The magnitude of competition is comparatively less between Agroforestry and Energy plantation, however in case of Agroforestry and Economic plantation the competition is mostly concentrated in high suitable areas.

3.5.2. Conflict resolution

Once the suitability maps of different land uses and combined together, we derive a multivariate composite data set of the land uses. This data set can be considered as a matrix where every pixel is having a suitability score for the identified uses. In a raster GIS environment every individual pixel is considered as an alternative (excluding the one that are left aside through constraint decision factors during suitability evaluation) and need to be chosen for a particular land use type. So at this stage it is interesting to investigate, whether these smallest land units i.e. the individual pixels are naturally classifiable into distinct groups based on the suitability scores. If we can derive such distinct groups that are homogeneous in nature with respect to their suitability for the particular land uses, hence provides a mechanism for conflict resolution and potential allocation.

3.5.3. Multivariate numerical classification

To achieve this objective a methodology has been developed to aggregate individual pixels of the raster data set into land suitability groups by gathering the pixels in accordance to their similarities of their suitability scores for the respective land use types. To execute this concept in a GIS environment we used the concept of multivariate numerical classification through divisive polythetic partitioning. The concept is based on hierarchical classification technique, where the whole dataset is divided first into two groups, and then the same process is repeated on each of the two classes identified at the first stage, then on each of the four classes identified at second stage, and so on. The objective behind this approach is to divide the entire dataset into two groups in such a manner that both groups derived are more homogeneous than the original parent group. Subsequent divisions create more homogeneous groups by further reducing the heterogeneity induced by association of multiple suitable land uses. The end result of the process yields groups that are maximally homogeneous internally, with attended maximum among group heterogeneity. Polythetic nature of the classification technique signifies that in the process of divisive classification all the available variables (suitability scores) form the basis for dividing a group into smaller groups.

From the theoretical point of view, a methodology based on both divisive and polythetic should be optimal to derive homogeneous groups of the land use systems based on their suitability scores. However only very few such methods have so far been suggested and these are computationally demanding. The demand of computational requirement arises from the fact that if there are ‘n’ pixels to pixels to be classified, then there are 2^{n-1} possible partitions of the samples into two groups. Even for small values of n (<100) this is computationally not feasible. To overcome this methodological hindrance we investigated an approach base on ordination space partitioning. In this approach at the first step we applied ordination technique to ordinate the data with no reduction of dimensionality and then break the first principle component into two. Ordination of the dataset helps to arrange the pixels in some coordinate frame to display their interrelationship.

3.5.4. Ordination space partitioning

In our approach, we capitalised the advantage provided by ordination techniques and devised our methodology to find the cluster of pixels in the ordinated space based on the suitability values and then applied divisive classification technique to segregate these clusters to form homogeneous groups. This method requires application of Principle Component Analysis (PCA) in successive steps (Fig: 3.10). At each step, the first principle component axis is divided into two separate groups. To achieve this, the suitability maps for all the three respective land use systems, that were derived through multicriteria analysis need to be stacked to generate the multivariate dataset and the above mentioned procedure can be performed using that data set to derive homogeneous groups. As discusses earlier instead of using the original suitability scores. We used a set of normalised suitability scores in a scale of 1(minimum) to 100 (maximum) for each of the land use systems for the multiobjective conflict analysis. This is important to eliminate the 'range effect' likely to occur due to the varied number of criteria considered for the suitability analysis of the land use systems.

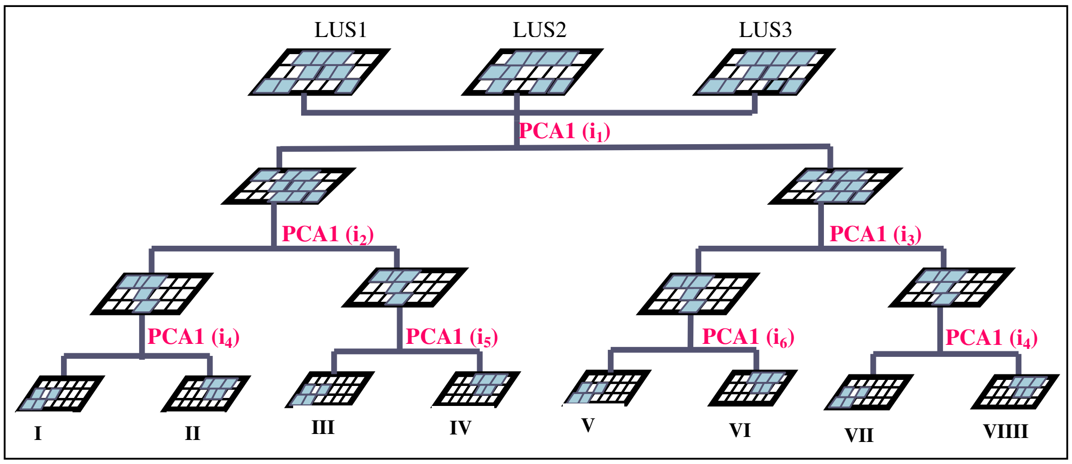


Figure 3.10:Numerical classification of the suitability layers of the three land uses by means of divisive polythetic partitioning

3.5.5. Deciding criteria for divisibility

In a GIS environment the ordination process can be performed using the principle component analysis functionality provided by most of the commercial GIS packages, however a significant issue related to the application of this approach is the choice of division point at ordinated axis.

To solve this issue we followed the approach called Noy-Meir's partitioning method referred by Pielou, 1984. According to this method the "break point" or the point where the principle component axis need to chosen so as 'within groups' component of variance is minimum. Eventually, the 'between groups' variance is maximal at this point, which can be found by trying the (n-1) possible divisions between adjacent values. This can be measured in terms of "increment of homogeneity", a criteria based on the difference average variance of the total data set and the sum of 'within groups" variance.

This concept is used at each step of division and the resulting clusters were obtained by calculating the grouping of pixels that maximized the "increment of homogeneity". This increment was computed by the following procedure:

1. The first principle component scores were divided in a frequency histogram
2. The histogram classes were placed into a series of two sets (for example, class one of the histogram class were placed in set 1 and the other classes in set 2, than class one and two were placed in set 1 and the rest in set 2, and so on). Table: 3.6 gives an example of the different combinations of breakpoints possible with 'n' number of classes of the histogram.

Table 3.6:Possible "break points"

Set 1	Set 2
1	2,3,4,5,…n
1,2	3,4,5,…n
1,2,3,	4,5,…n
1,2,3,….(n-1)	n

3. The increment of homogeneity was calculated by the pairwise comparison of the sets, using the following formula:

$$\Delta\sigma = \sigma_t - (\sigma_1 + \sigma_2)$$

Where,

$\Delta\sigma$ = Increment of homogeneity

σ_t = Average variance of all the first principle-component scores classes

σ_1 = Variance of the set 1 of first principle-component scores classes

σ_2 = Variance of the set 2 of first principle-component scores classes

In this process application iterative principle component analysis classified subset or groups of pixels were obtained, these groups are homogeneous with respect to their suitability for the land uses. The subsets of pixels or groups obtained from numerical classification were than transferred to nominal maps that represent their spatial distribution.

Numerical classification for the case study area yielded eight groups with seven PCA iterations (Fig: 3.10 and Fig: 3.11).

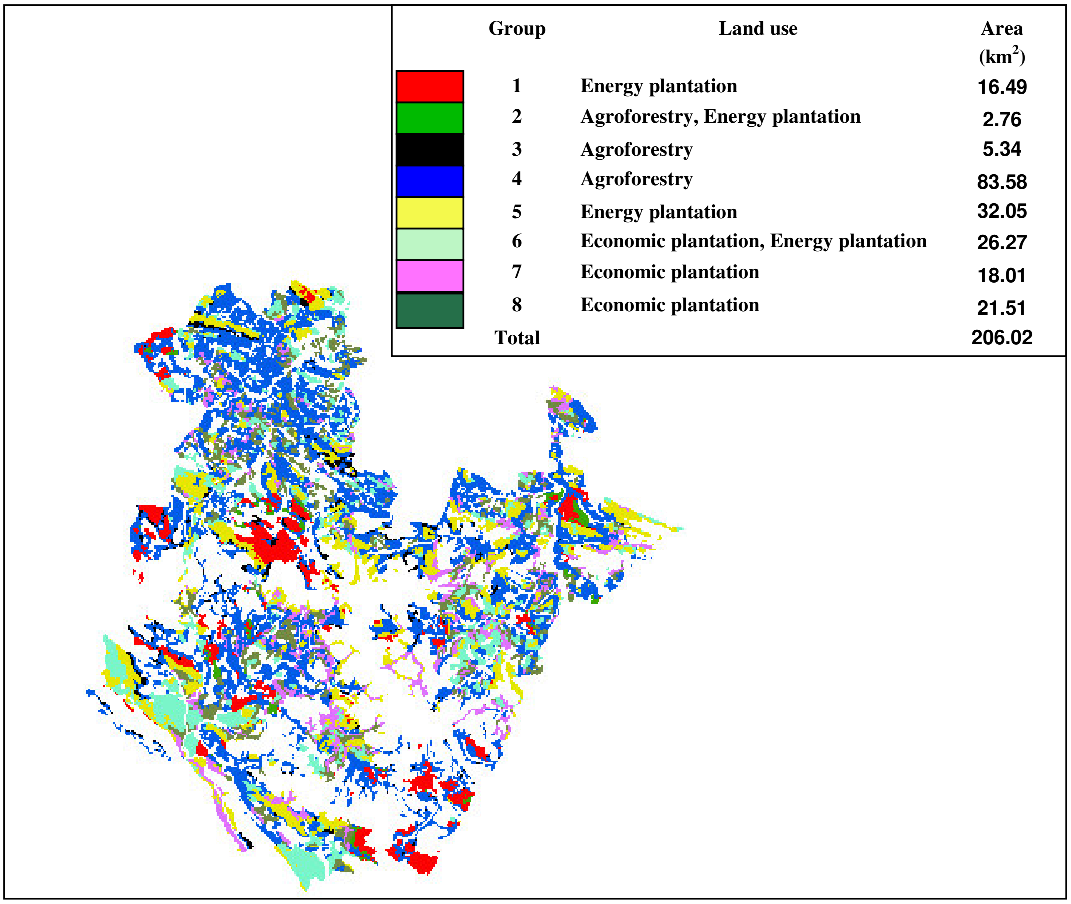


Figure 3.11:Land suitability groups for the case study area

3.5.6. Conflict resolving and allocation

At the next stage a matrix of mean group suitability (**Z**) (Table: 3.7) generated to compare the relative suitability among the groups and ‘conflict resolution index’ were developed to compare the relative competition among the groups.

Table 3.7: Mean group suitability scores

	Agroforestry	Economic plantation	Energy Plantation	Group Mean
Group1	2.7984	2.8748	42.504	16.05907
Group2	60.2675	0	70.7107	43.6594
Group3	18.5293	0	0	6.176433
Group4	47.717	0.0818	0.771	16.18993
Group5	5.2117	0.0816	35.9982	13.76383
Group6	0.5689	85.5009	67.2077	51.0925
Group7	50.527	72.886	44.454	55.95567
Group8	60.5917	92.0198	71.2872	74.6329
Land use Mean	30.7764375	31.6806125	41.6166	

The matrix (**Z**) was standardized by double centring procedure (Digby et al., 1987, Bojorquez-Tapia et al., 1999, Bojorquez-Tapia et al., 2001) for both land use and groups.

$$\mathbf{Z_{gl} = X_{gl} - X_g - X_l + X_a} \qquad \text{Equation (3.3)}$$

Where,

$\mathbf{Z_{gl}}$ = Conflict resolution index or the adjusted mean land suitability
$\mathbf{X_{gl}}$ = Mean suitability score of group 'g' for land use 'l'
$\mathbf{X_g}$ = Mean suitability score of group 'g'
$\mathbf{X_l}$ = Mean suitability score of land use 'l'
$\mathbf{X_a}$ = Mean suitability score of the whole matrix

A positive value of '$\mathbf{Z_{gl}}$' indicates a high mean suitability of group 'g' for land use 'l', while a negative value denotes the opposite (Fig: 3.12). In conformity with multi-objective theory and the area multiple use concept conflicts are predicted when two or more land use with competing interactions shows a high relative suitability for the same tract of land. Conflicts among the land use systems can be identified by examining which groups derived through the above-mentioned methodology presented a positive value of conflict resolution index for two or more competitive land use systems.

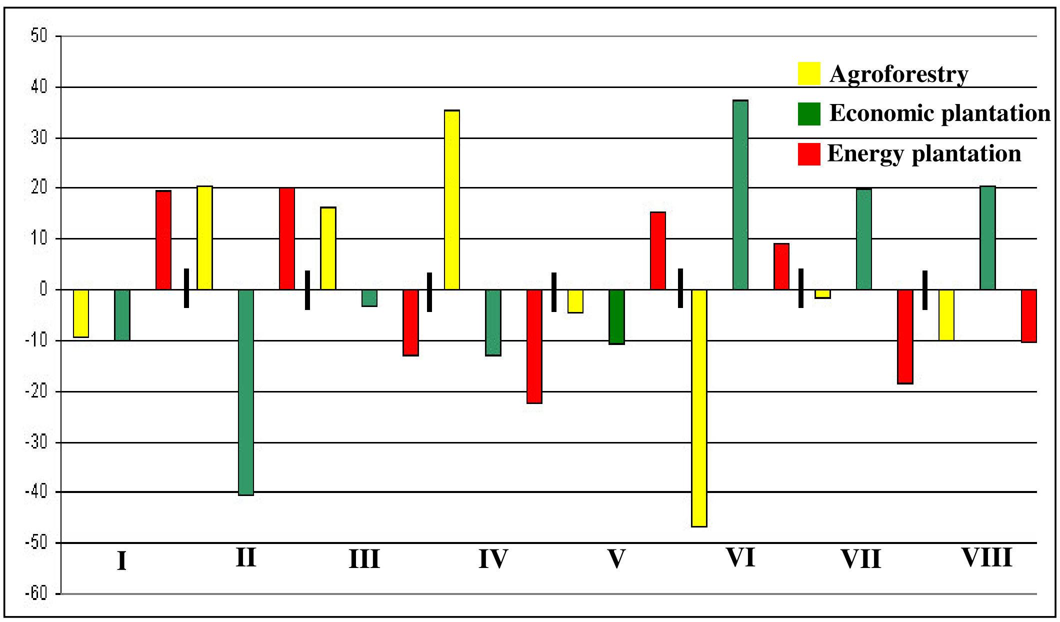


Figure 3.12: Conflict resolution indexes for land suitability groups

Comparing the 'conflict resolution index' between the land use systems revels the intensity of a conflict, because 'conflict resolution index' reflects the degree of suitability of a land use for a particular tract of land in this case represented as groups derived through classification (conflict resolution index compare simultaneously the land uses and land suitability groups)(Fig: 3.12).

In this regard it's worth mentioning that, the 'range effect' that might occur in the multicriteria suitability evaluation, as in case of different land use systems the number of criteria considered was different, does not influence the multiobjective analysis and group generation. This point has been taken care the beginning itself by normalising the suitability maps into the 1 to 100 suitability scale. The process of numerical classification it is also assumed that all the land use systems has the equal importance. The graphical display of these indexes makes it easy and convenient interpretation and synthesis of the conflicts through examining the values of 'conflict resolution index' of each land use systems in each group consequently helping to determine the likelihood and potential intensity of conflicts among the land use systems.

Group wise comparative analysis of the conflict resolution indexes for the respective land use clearly indicated the suitability of the group with respect to the land uses. For example in Fig: 3.12 we can see that for the group I the conflict resolution index value of energy plantation dominate completely over other land uses. Therefore can be inferred very conveniently that for the group I energy plantation is the most suitable land use. In the same way we can identify the suitable land use for group III, IV, V, VII, VII (Fig: 3.12) as in all of these cases we could derive the grouping through numerical classification in such a manner that they show positive value of conflict resolution index for only one land use. In such cases we can straight easily decide upon the land use type that should be assigned to that particular group. However for the group II and group VI (Fig: 3.12) decision about the allocation of land use for that particular group is not that straight forward. In both of the cases we can see that the groups represents more than one positive value of conflict resolution index for the respective land uses. This indicates that though our objective was to derive homogeneous groups of land uses, in such groups still we can find heterogeneity in terms of suitability for the land uses. Comparative analysis of the conflict resolution index values indicates that in-group VI (Figure: 3.12) though both the land uses (i.e. economic plantation and energy plantation) has a positive value, the value for economic plantation is quite higher than the value for energy plantation.

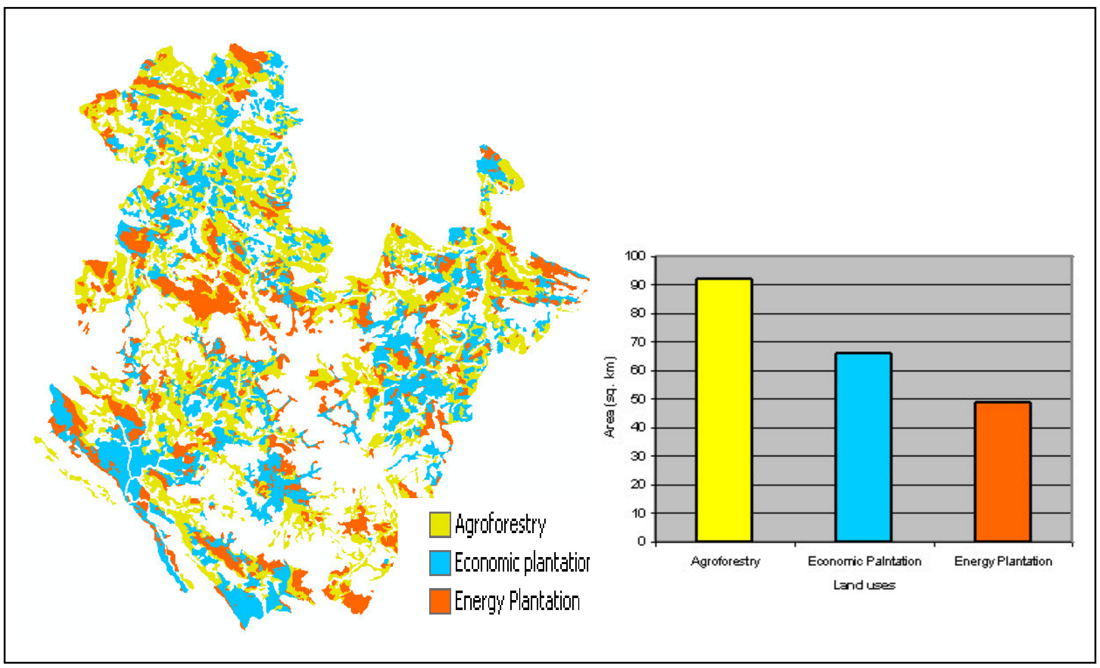


Figure 3.13: Potential allocation of the alternative land uses

This indicates that the relative competition is of lower intensity and the group can be assigned to the land use that indicates higher value of conflict resolution index. Where as in case of group II (Figure: 3.12) both the land uses have values of conflict resolution index in a very close range, indicating that the intensity of conflict is quite high among these land uses consequently making the process of allocation more difficult. However in case of our case study we decided to assign the group to the land use that shows the higher value among the two.

The potential allocation map (Fig: 3.13) indicates that 91.68 sq. km area is suitable for Agroforestry activities, 65.78 sq. km area is suitable for Economic plantation and 48.54 sq. km area is suitable for Energy plantation. The pattern of allocation obtained by the application of multivariate statistical analysis represents the areas that are suitable for the respective land uses. The approach allocates the sites to the respective land uses on the basis of the mean suitability scores of the resulted groups. The land use for which we derive the height positive value of conflict resolution index is considered as the most suitable use for that particular group. This decision is justified based on the fact that the assignment of the individual pixels in to homogeneous groups is not only based on individual suitability scores but the process also takes the suitability scores of the neighbouring pixels. Hence the process helps to maintain spatial contiguity and compactness while deriving the groups.

In this case study, we had taken a simple assumption that, the allocation of the land uses is purely based on their suitability. Based on this assumption we assigned the land uses to the groups and came up with a potential allocation scenario. A simple visual observation revels that we could achieve the requirement of maintaining spatial continuity in allocating the land uses as we can see that the areas suitable for a particular land uses is appearing as groups and not in a very scattered manner. However the most important fact is that the allocation of the uses is based on their suitability performance. However it is acknowledged that the actual pattern of allocation of the land uses in reality will be governed by a combination of several factors besides the suitability of the land use alone. This approach can be customised and extended to address such requirements, demand for a particular land use and potential area requirement for that land use can be incorporated in the approach.

In this chapter, we used the conceptual background discussed in Chapter 2 to develop and test an integrated approach for land resource planning that involves Spatial modelling and application of multicriteria evaluation techniques. The framework of the methodology is divided in four phases: the first phase deals with identification of land uses alternatives based on physical and socio-economic situation analysis of the study area. The second phase deals with multicriteria land suitability evaluation for the alternative uses. In this phase we investigated two different multicriteria decision making techniques in a GIS environment. The idea behind using two different techniques is to investigate the difference in decision outcomes due to technique bias. Integration of multicriteria decision-making techniques in GIS environment for land suitability modelling provides an efficient mechanism to integrate objective and subjective information, which is absolutely necessary to model the process of decision making and planning. In the third phase we addressed the issue of multiobjective conflict resolution and allocation. Here, we investigated a new approach based on multivariate statistical analysis. The major advantages of the approach are that, it can derive optimal pattern of allocation with minimum spatial data; derived results are easily interpretable by the decision makers; can address the computational complexities associated with multiobjective decision making techniques.

4. Chapter IV: System Design and Development

The concept for Spatial Decision Support Systems (SDSS) evolved out of the need to provide geographic information systems (GIS) users with the proper set of tools to resolve complex geo-analytical problems. SDSS are considered as tools to aid decision making with problems that are not well structured. Justification for the use of such systems is the need of iterative and recursive mechanism to select the appropriate alternatives in achieving the solution for a particular decision problem. The generic framework for such a system involves several problem-solving activities, such as building the database, developing the multicriteria value structure (the relationships between objectives, attributes and decision maker's preferences), generating decision alternatives, and choosing the optimum alternatives for implementation. Traditionally all these functionalities have been implemented in a computer environment as a separate technology. For example, GIS provides an efficient and effective environment for supporting spatial data manipulation and analysis. The MCDM techniques are focused to assist in structures decision-making. However the objective of SDSS is to provide these facilities in an integrated environment to help users to explore the decision problem in an iterative and recursive fashion.

Due to the time limitation, a fully operational SDSS with a user-friendly graphical interface could not be developed. However an attempt has been made to develop the conceptual design of the system and also to develop some of the components that were used for the case study. Here we will discuss about the fundamental concepts that were taken into consideration while developing the design of the proposed system.

4.1. Introduction to System Development

The development of SDSS most frequently focuses on assembling a collection of tools such as geographical database for storage and analysis of geographic information, some models to support structured decision analysis and some visualisation systems. The design therefore has a strong architecture orientation, where the architecture is defined by the set of functions present, their assignment to components and subsystems and the interconnections between them.

For a good understanding of the system design it is important to understand the requirements of the application, that in turn guide the selection of models and model management system, database and database management system and user interface in a manner that best meets the requirements for that application. Physical design of a successful decision support system must follow a logical design, which is in turn must be guided by the decision making process. While developing the logical design emphasis is given to identify the potential users and their requirements. This helps to specify the requirements of the system and guides the designers to develop the system in a manner to suit the user requirements.

Before starting with the actual design of the system the following questions need to asked and analysed by the designer(s):

What is the purpose of the system?
Who are the potential users of the system?
Why such a system is needed?
What advantages does the user expect from the system?
Where does the system fit in to the existing decision making processes?

Analysis of the findings form these questions give the designer a clear idea about the users of the system and their requirements. This also helps the designer to understand the decision-making process and the general style followed by the users. These information help the designer to conceptualise the system requirements and the logical sequence of design.

4.2. User requirement analysis and specifications

The first stage in designing of a SDSS is to learn about the decision needs and environment. Designer(s) need to know the key decisions under consideration by the decision maker and the related information needs. The process starts with the identification of the parameters needed for consideration. To this end the most important issue is to identify the users and their requirements. Once the designer is aware of the user requirements, the next job is to translate these requirements into system specifications. That follows prototype development and testing. In all these phases close interaction and feedbacks from the potential users plays important role to design and develop the system in a desired way and also to address the issue that may arise during these phases. For this research we tried to follow a protocol based on the system development lifecycles to conceptualise the design of the intended software and the task of system design and development is dived in to four phases:

(1) Identification of users & requirements analysis
(2) Developing system specification
(3) Design and development of the system and program
(4) System testing

4.2.1. Identification of users and requirement analysis

An important phase in system development and design is to identify the potential users and to know about their requirements. Analyse the requirements can be achieved by using any of the following two techniques. Formal information analysis can be used to establish models of the information flow and structure. These models are then expanded to become a software specification. Alternatively, a prototype of the software is built and evaluated by the potential users in an attempt to solidify the requirements. This is a joint effort conducted by the designer and the potential users.

After analysing the land resource planning and decision-making framework in Indian context, we decided to aim at officers comprising extension officers; regional agricultural scientists and district level administrative officers from at District and Block level agencies as potential users. They are the key decision makers at these levels and suppose to make the land use plans and take appropriate actions.
Detailed discussion and series of interviews with the potential users helped us to identify the user requirements. This lead us to the conclusion that the SDSS for land resource planning would be an automated system, applied to problems at the district or block level, that would assist a decision maker at these level to make land use zoning and intervention decisions. Interactions and discussions

with the potential users revels the fact that the system need to be very user friendly in nature as most of the potential users and decision makers are not well aware of the advanced computing technology. The system needs to be supported with a well-equipped graphical interface and strong documentation to make it easy to use for the planers and decision makers.

4.2.2. Developing system specifications

Once the user requirements are analysed and understood, the next phase consist of translating theses requirements into system specifications. The takes undertaken during the system specification stage consists translation of user requirements into a description, and a schematic of the proposed system and its data requirements.

Translation of the user requirements into system specification reveals that the decision support systems should be able to provide integration and regeneration of the information. It should also support the exploratory nature of the discovery process and allow the development of alternatives in order to increase the effectiveness of those responsible for decisions. In such cases the computer can support and reinforce human judgement in the fulfilment of tasks. Considering these general frames of functionalities we can infer that the intended SDSS need to provide the following capabilities and functions:

- ❖ Mechanisms for spatial data manipulation and analysis
- ❖ Procedures for multicriteria suitability assessments
- ❖ Procedures for multiobjective conflict resolution and allocation
- ❖ Statistical data analysis and visualisation tools
- ❖ Provide output in a variety of spatial forms including maps

To support these functionalities the SDSS need to integrate different techniques in a single computer environment. The different components should be integrated in such a manner that the components can share data and control execution of problem solving tasks. The spatial decision support system for land resource planning and management need to have the following components:

- ❖ Geographical data management and analysis tools
- ❖ Multicriteria decision analysis models
- ❖ User interface

4.2.2.1. Geographical data management and analysis tools

This consists of the data base management system for storage and manipulation of geographical data. The fundamental consideration in designing the GIS bases SDSS data module is the compatibility of the data constructs between the GIS/ DBMS model and the MCDM modelling system. In this end, a grid based spatial construct provides a convenient data model for reprinting attribute data in tabular format (decision matrix) that can serve as data input for the multicriteria modelling. Geographical data management and analysis tool set also needs to support the full range of basic and advanced GIS functionalities. The Geographical data management and analysis tool sets also need to support exploratory data analysis, statistical and mathematical tools to supplement the decision-making tools supported by the MCDM models. This helps the decision makers to with a better understanding of the decision situation.

The focus here is to develop a SDSS for land suitability evaluation and allocation of land resources. The important requirement of the system is the capacity to incorporate spatial data Hence one of the main components of the system is a GIS therefore the development is be done taking the GIS system at the core and integration other sub models around it. We used the ArcInfo GIS for geographic data management and analysis. Considering the fact that speed of overlay and buffer operations within a raster based GIS greatly outperform their vector-based counterparts, raster data model and cell based data processing methods were primarily utilized for this research.

4.2.2.2. MCDM tool sets

Multicriteria decision making techniques are characterised with a diverse set of methodologies. In this research we applied two different kinds of multicriteria analysis techniques. Multiattribute attribute decision-making (MODM) technique was applied for land suitability analysis and Multiobjective decision making (MODM) technique was applied for conflict resolution and allocation. So the intended system should incorporate these two different MCDM models as subsystems.

Most of the GIS software supports programming environment. With the application of such programming environment external programmes can be developed and can be integrated in the GIS. For instance ArcInfo provides AML as its scripting language that can be used to develop external programmes and incorporated into it. ArcInfo also provides ODE environment, the advantage of this is that AML scripts can be activated from other interfaces developed using other programming languages like Visual Basic.

To perform multicriteria land suitability analysis we employed two distinct methods: Spatial AHP and Spatial compromise programming. Both the methods can be implemented in a GIS environment. For AHP a separate programme can be developed using any programming language (viz. Visual Basic) that provides the functionalities for generating the pairwise comparison matrix, calculating the relative weights. The output from this programme need to transferred in to the GIS environment to incorporate the results in spatial analysis. Alternatively any MCDM software package that supports AHP can also be integrated with the GIS through coupling mechanism. The compromise programming method can be directly implemented in the GIS environment; the only additional development it requires is to write a programme for criteria standardisation. This can be achieved by writing a program using AML and providing as a menu in the interface of the GIS.

To perform multiobjective conflict resolution and allocation, the methodology makes use of multivariate statistical analysis. Such functionalities like Principle Component Analysis (PCA) are directly supported by majority of the GIS software. The only thing required is to develop an interface for these procedures to make the operations user friendly for the decision makers. The interface can be developed in such a manner that it hides the complex statistical operations from the users and guide them through out the process with interactive help and tips.

4.2.2.3. User Interface

The interface designed in the SDSS needs to provide a dialogue environment between the system and users. Considering the less exposure of the planners and decision makers at the regional level to advanced computing technology the development of the system need to be guided by the principle of "user friendliness". Hence the system's user interface component of the SDSS needs to be developed based on the behaviour and style of decision making of the decision makers. The system's user interface should be easy enough for decision makers to input their concepts of a decision space and problem. For decision makers, the interface of the system is the only access point to the database and models. In dealing with spatial decision-making, the quantity of data is huge and the models are complex, so a sensible interface design is foremost in making the system user-friendly

Since the system will be developed taking GIS software as base the user interface of the GIS software will be available for the users. However the interface can be customised for the specific purpose using the macro language of the GIS software to suit the user needs and to give a user-friendlier platform.

4.3. Design and development of the system

System design is the step of process modelling and data modelling. The design of the system is based on the information gathered through literature and current situation analysis. To be an efficient decision aid tool the application requires appropriate data model i.e. the data required to support the decision making process should be structured in such a way that they can be handled by GIS functions to provided required information. The process modelling aspect deals with the developing the models for the different decision making techniques and developing programmes for them so that it can be integrated to the GIS.

Conceptual data model of database

Conceptual data model is the first level of abstraction from reality. It consists of describing how the spatial and non-spatial data can be linked in a database, how the data about reality can be abstracted and represented in database. Review of literature reveals that a relational data model is most suitable for linking spatial and non-spatial data.

A database, containing the physical and socio-economic information for the case study area is developed and used for the case study. The database contains both spatial and non-spatial on the study area. The database is created using ArcInfo GIS software and each individual themes are stored as ArcGrid file. The choice of raster data format was done based on the consideration that it makes easy to export and import of data from GIS and MCDM models.

During the implementation of the methodology we also developed models for multicriteria and multiobjective decision-making and incorporated them in the GIS. For multiobjective conflict resolution we developed a programme using the programming environment of ArcInfo to automate the process. A user interface was also created for the same.

5. Chapter V: Conclusions & Recommendation

This chapter discusses the extent to which the research objective and research questions been met and answered. The discussion focuses on applicability of the methodology for multicriteria land suitability assessment and multiobjective conflict resolution for planning and decision-making. The other discussions focus on applicability of the methodology in other situations and generality of the research results. Finally recommendations for further research are elaborated.

❖ **Have the objective of the research been met?**

As outlined in Chapter one, the study is intended to develop a methodology for land resource planning involving multiple conflicting uses and to address this issue an approach will be evolved to integrate MCDM techniques in GIS environment.

Based on the discussions and observations outlined in the earlier chapters, it can be inferred that the complexity and multidimensionality associated in the process of land resource planning and decision making is contributed by the following diverse requirements of the process: a) involvement of objective and subjective information in decision-making b) require integration of data and information from wide spectrum of disciplines c) it involves expert’s knowledge d) needs inputs from different stakeholders and assessment from different experts e) need for identification of conflicts and methodology to resolve them. Here we discussed whether the proposed methodology could address these requirements successfully.

Integration of MCDM techniques in GIS environment facilitates integration objective and subjective information from diverse sources. The methodology incorporates knowledge, value and judgement of stakeholders, experts and decision makers in the process of decision-making. This provides a more realistic approach for such tasks, as compared to the simple data driven conventional approaches. Complexity and multidimensionality of land suitability assessment could be addressed with the application of multicriteria techniques. Application of multivariate statistical analysis could address the problem of conflict resolution and allocation successfully by proving results that are easy to understand, while mathematically rigours at the same time.

❖ **Answers to the research questions**

Research question 1:
How to decide the potential land use alternatives?

The major role of planning and decision-making is to the address socio-economic needs and priorities. The process of identification of potential decision (land uses) alternatives was based on information from various domains (physical, social, economic) and of different nature (soft, hard). To this end, proper situation analysis was done for the case study area to identify the relevant interest groups, problems and prospects of the area and the specifications of the identified land use alternatives. This provided a reasonably strong knowledgebase to be used as intelligence in rational planning and decision-making.

However limited availability of socio-economic data was an inevitable constraint in the case study. To make consensus among different groups advanced techniques like Delphi method, Participatory rural appraisal (PRA) method can be used within the framework of this methodology to further strengthen the final decision outcomes.

Research question 2:

How to incorporate expert knowledge and decision maker's judgments in the process?

Determining the decision factors and their relative importance are two crucial phase in the methodology. Expert knowledge on the ground process and of the relevant discipline played an important role in the process. A major advantage of the methodology is the mechanism it offers to incorporate expert knowledge and judgements of the decision makers in suitability analysis. This methodology can also be extended to group decision-making domain by considering the group opinion. Conversion of the decision problem into hierarchical structure based on expert knowledge helps the decision makers to structure the complex problem and also helps to trace back if any flaw occurs in decision making process.

To tackle of biasness from the part of the decision maker, an approach based on cognitive mapping can be taken up. This makes the process more transparent and reduces the chances of bias. Various researches in the field of modelling expert knowledge, analysis and reducing uncertainties in expert judgements are on in the scientific communities. The findings from such studies can be integrated with in this methodology to overcome the possible shortcomings regarding the quality of the analysis results.

Research question 3:

Which MCDM technique(s) should be adopted in the suitability analysis model and optimal allocation model for competing land use alternatives?

The issue of converting the spatial and non-spatial data in to value judgement can be tackled satisfactorily within the framework of this research. The decision variables considered were converted into value judgments using relative preferences defined by the experts and aggregation was done using spatial AHP and spatial CP.

Techniques for multicriteria land suitability analysis

Considering the diverse verities of MCDM rules, the question of choosing the appropriate method(s) is an important factor. It is observed that the different multicriteria evaluation rules generate considerably different outcomes. To investigate this issue we considered two different MCDM approach in this research to find the contribution of technique bias. The application of Analytical Hierarchy Process (AHP) method is justifiable in this research as it provides a structured, yet flexible approach to decision making. It also allows critical examination of the underlying assumptions, inconsistency of value judgments and facilitates the identification of tradeoffs. Application of compromise programming (CP) provides mechanism to judge the significance of compensatory characteristics of the technique. The comparative study also helps to understand the contribution of technique bias in decision outcome.

Technique for multiobjective conflict resolution and allocation

Conflict resolution and generation of potential spatial pattern for land use allocation require some analytical process that is simple and easy to understand, but mathematically rigorous at the same time. The approach followed in this research fulfils both the requirements. Although numerical classifications are mathematically complex, the results of the multicriteria analysis are easy to understand. The analysis only identifies the areas (called suitability groups) that are homogeneous with respect to their suitability scores for the involved groups.

The procedure also contributes to improve upon the limitations of other multiobjective optimisation approaches based on either linear programming or heuristic optimisation. The former is subjected to the limitation of number of decision alternatives that it can handle efficiently and this poses as barrier for integration in GIS environment. The later approach though used extensively and can handle much larger no of decision alternatives cannot guarantee an optimal solution. Another problem associate with these methods, that they do not assure a spatial pattern with contiguity or compactness in land allocation for different land use types. The application of multivariate numerical classification solves both the problems and can provide an optimal solution for land use allocation.

Computational complexities associated with the multiobjective methods that make them difficult to implement in the GIS environment is also successfully addressed in this research using principal component analysis. The functions required for implementing the multiobjective conflict resolution and allocation process are available in majority of the commercial GIS software, hence developing mathematical programming algorithms or integrating other special commercial optimisation package is not required.

Research question 4:

How MCDM technique(s) can be integrated with geospatial modelling to design a prototype framework for SDSS?

GIS was used as the core of the integrated system and the MCDM models were integrated to the GIS using the programming facilities provided by the GIS software. It provided the framework for the spatial decision support system. The MCDM techniques were developed and used with in the GIS framework. It helps to overcome the limitations of classical Boolean operations and weighted linear combination (WLC) methods by enabling representation of facts and value judgements in a right combination. However, a fully functional SDSS integrating all the components could not be developed yet.

Recommendation for future research:

This research should be continued with the development of an operational spatial decision support system for land resource planning and management. The immediate recommendation is to develop a user-friendly interface to integrate all the components in a single interactive environment to make the evaluation process a uniform, transparent and demanding less technical effort from decision makers.

Since a small number of socio-economic factors have been considered for the evaluation of land suitability, it is recommended to incorporate more factors from this domain to represent a holistic view of the actual process. The research can be extended to explore the potentials of advanced visualisation techniques and exploratory data analysis methods to aid knowledge discovery for decision-making purpose.

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Appendix-A

Decision hierarchy for land use suitability assessment:

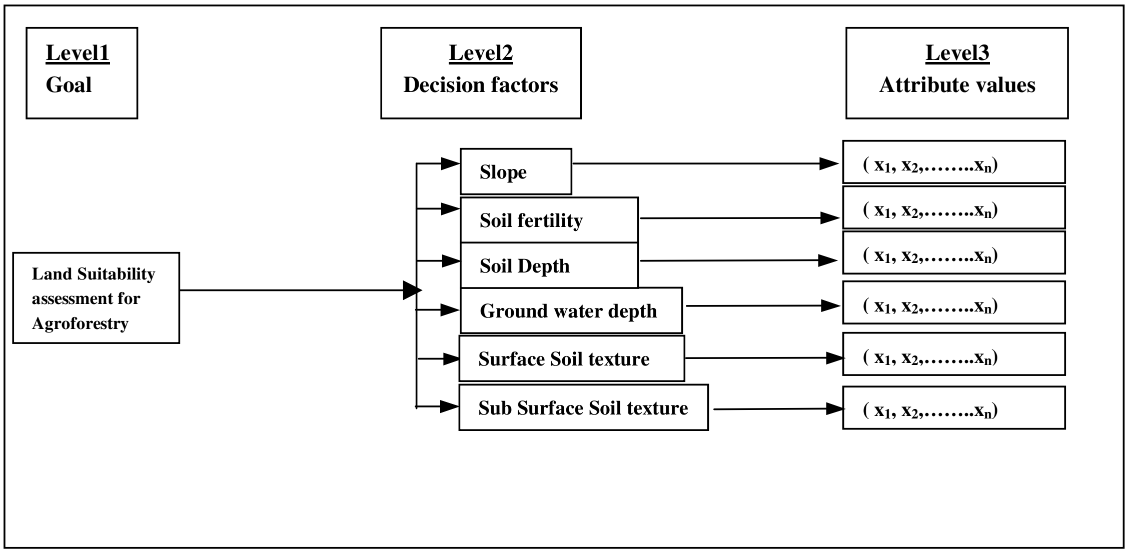
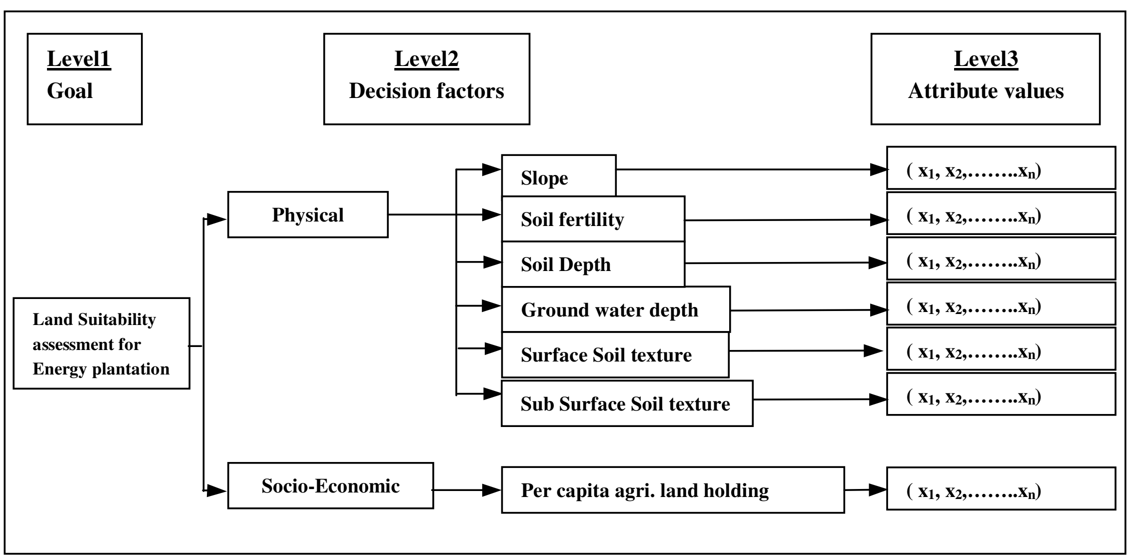


Figure A.1:Decision hierarchy of land suitability assessment for Agroforestry



FigureA.2:Decision hierarchy of land suitability assessment for Economic Plantation

TableA.1:Relative weights of the attributes associated with the criterions for suitability assessment of Agroforestry

Criteria: Slope		Criteria: Ground water depth		Criteria: Soil depth	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
<1%	0.4059	5-25meter	0.4830	50-85cm	0.0393
1-5%	0.3645	15-35meter	0.3112	65-150cm	0.1259
5-15%	0.1325	20-35meter	0.1185	85-165cm	0. 2696
15-25%	0.0651	20-45meter	0.0623	>150cm	0.5650
25-35%	0.0320	30-45meter	0.0250		
Criteria: Surface soil Structure		**Criteria: Sub surface soil Structure**		**Criteria: Soil fertility**	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
Loam sand to sandy loam	0.0298	Sandy loam	0.0253	High	0.6296
Sandy loam	0.0484	Sandy loam to loam	0.0405	Medium to high	0.2431
Loam to sandy clay loam	0.0974	Sandy loam to sandy clay loam	0.0590	Medium	0.0919
Sandy loam to silt loam	0.2303	Loam to silt loam	0.0959	Low	0.0355
Sandy loam, silt loam and loam	0.2766	Loam to clay loam	0.1497		
Sandy loam to sandy clay loam	0.3174	Clay loam	0.2274		
		Sandy clay loam to clay loam	0.4020		

TableA.2:Relative weights of the criterions for suitability evaluation of Agroforestry

Land Use	Slope	Ground water depth	Soil Depth	Surface soil texture	Sub surface soil texture	Soil fertility
Agroforestry	0.3258	0.2556	0.1896	0.0690	0.0969	0.0628

TableA.3:Relative weights of the attributes associated with the criterions for suitability assessment of Economic plantation

Criteria: Slope		Criteria: Ground water depth		Criteria: Soil depth	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
<1%	0.0651	5-25meter	0.1185	50-85cm	0.0393
1-5%	0.1325	15-35meter	0.3112	65-150cm	0.1259
5-15%	0.4059	20-35meter	0.4830	85-165cm	0.5650
15-25%	0.3645	20-45meter	0.0623	>150cm	0.2696
25-35%	0.0320	30-45meter	0.0250		
Criteria: Surface soil Structure		Criteria: Sub surface soil Structure		Criteria: Soil fertility	
Attribute classes	Weights	Attribute classes	Weights	Attribute classes	Weights
Loam sand to sandy loam	0.0974	Sandy loam	0.0959	High	0. 3431
Sandy loam	0.0298	Sandy loam to loam	0.2274	Medium to high	0.4296
Loam to sandy clay loam	0.0484	Sandy loam to sandy clay loam	0.4020	Medium	0.1919
Sandy loam to silt loam	0.2766	Loam to silt loam	0.1497	Low	0.0355
Sandy loam, silt loam and loam	0.2303	Loam to clay loam	0.0590		
Sandy loam to sandy clay loam	0.3174	Clay loam	0.0253		
		Sandy clay loam to clay loam	0.0405		
Criteria: % Agricultural land holding					
Attribute classes	Weights				
Very Low	0.4059				
Moderately low	0.3645				
High	0.1325				
High	0.0651				
Moderately High	0.0320				

TableA.4:Relative weights of the criterions for suitability evaluation of Economic plantation

Land Use	Slope	Ground water depth	Soil Depth	Surface soil texture	Sub surface soil texture	Soil fertility	% Agricul-tural land holding
Economic Plantation	0.0435	0.2544	0.0845	0.0389	0.1409	0.1091	0.3286