Development of a Range Management Decision Support System (RAMDSS) for forest planning in the Banavasi Range of the Western Ghats, India.

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Dedicated to my Parents

Declaration

This thesis has been composed by myself and it has not been submitted in any previous application for a degree. Myself have executed the work contained, unless otherwise indicated.

Abstract

The alarming rate of depletion and degradation of forest resources has made it increasingly important to develop a better and more efficient approach to forest planning and management. Forest planning requires the integration of large volumes of disparate information from numerous sources. It demands the coupling of this information with efficient tools for assessment and evaluation in order to permit broad, interactive participation in the planning, assessment and decision-making processes. Currently, no single method or technique can address all of these requirements credibly and satisfactorily. However, modern technologies such as Spatial Decision Support Systems (SDSS), which are an integration of many sub-systems, including Geographical Information Systems (GIS), analytical models, user interfaces, Relational Data Base Management System (RDBMS), and Knowledge Based Systems (KBS), could have the necessary power and flexibility.

In this project, a RAnge Management Decision Support System (RAMDSS) has been developed to assist the forest manager in improving day-to-day planning processes in a case study of the Banavasi Range of the Western Ghats, India. In this prototype, three major data types were collected namely, spatial data such as administrative boundaries, soil, contours, forest land use/cover, geology and geomorphology, non-spatial data such as socio-economic, and forestry inventory, and finally knowledge provided by experts and from the published literature. In the prototype RAMDSS, all of this information was made available through a common platform using different techniques and technologies, which included satellite remote sensing, RDBMS, GIS, a Graphical User Interface (GUI), visualisation and KBS. The detailed development stages in the RAMDSS include assessment of user requirement, data collection, conceptual design, implementation and testing of the system.

The functionality of the system includes three major modules: *Data Manager, Model Manager* and *Display Manager*. The first module allows the user to collect, edit, query and visualise the existing database. The customised user interface in the second module, which provides modelling capability, enables managers and end users to run different models, test alternative strategies and if necessary make the appropriate decisions for planning and management. The final module helps the user to view the output in the form of maps, tables, graphs and reports. The methodology used to develop the prototype in this project can assist the managers in effective forest planning not only for the study area but also globally.

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Acronyms

AI	Artificial Intelligence
ANN	Artificial Neural Network
AVHRR	Advanced Very High-Resolution Radiometry
CCF	Chief Conservator of Forest
CF	Conservator of Forest
CIFOR	Centre for International Forestry Research
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSDM	Collaborative Spatial Decision Making
DBMS	Data Base Management System
DDE,	Data Dynamic Exchange
DFD	Data Flow Diagrams
DFO	District Forest Officer
DLL	Dynamic Link Library
DSS	Decision Support System
EOSAT	Earth Observation Satellite
EROS	Earth Resources Observation System
ERS-1	ESA Remote-sensing Satellite-1
ERTS	Earth Resource Technology System
ES	Expert Systems
FAO	Food and Agricultural Organisation
FCC	False Colour Composite
GEMS	Global Environment Monitoring System
GIS	Geographical Information System
GMS	Geostationary Meteorological Satellite
GUI	Graphical User Interface
HS	Hyper-text Help System
IRS	Indian Remote Sensing Satellite
ITTO	International Tropical Timber Organisation
IUCN	International Union for Conservation of Nature and Natural Resources
IUFRO	International Union of Forestry Research Organisations
KBMS	Knowledge Based Management System
KBS	Knowledge Based System
KFD	Karnataka Forest Department
KR	Knowledge Representation
Landsat	Land Satellite
LISP	List Processor
LISS	Linear Image Self Scanner
LULC	Land Use and Land Cover
Meteosat	Meteorological satellite
MIS	Management Information System
MLC	Maximum Likelihood Classifier
MMS	Model Management System
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NCGIA	National Centre for Geographical Information and Analysis
NGO	Non-Governmental Organisation

NOAA	National Oceanic and Atmospheric Administration
ODA	Overseas Development Authority
ODBC	Open Data Base Connectivity
PC	Portable Computer
PPST	Project Process Development Programme
PROLOG	Programming in Logic
RAMDSS	Range Management Decision Support System
RAP	Rapid Application Prototype
RFO	Range Forest Officer
RMBMS:	Relational Model Base Management System
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SDSS	Spatial Decision Support System
SFM	Sustainable forest management
SOI	Survey of India
SPOT	Systeme Pour l'Observation de la Terre
SQL	Structured Query Language
TFAP	Tropical Forests Action Programme
TM	Thematic Mapper
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Programme
USGS	United States Geological Survey
VR	Virtual Reality
VRML	Virtual Reality Markup Language
WCMC	World Conservation Monitoring Centre
WRI	World Resources Institute
WTO	World Trade Organisation
WWF	World Wide Fund for Nature
WWW	World Wide Web

Chapter 1: Introduction

1.1. Research context

This thesis is concerned with the development of a Decision Support System (DSS) for forest planners in order to assist them in the day to day planning process. The rationale behind this research is to identify what are the problems with present-day forest planning? Further, how may these problems be solved using a DSS? The research described here is therefore at the junction between the fields of forest planning and development of DSS. The first section explains in detail the need for information systems in tropical forest planning and management. The second section explains the need for development of DSS for forest planning and the final section considers the aim and objectives of the thesis in the light of their contribution to resolving these issues.

1.2. Tropical forest planning and management

Tropical forests are extremely rich ecosystems that support a disproportionately large share of the world's plant and animal species. These forests have been and are being threatened by uncontrolled degradation and conversion to other types of land uses, influenced by increasing human needs notably through agricultural expansion. Growing concern about the state of the world's tropical forests has led to widespread calls for changes in the way forests are managed, requiring prudent planning and management of the existing forest (Evans, 1997; FAO, 1999).

The Western Ghats of India (the study area) form one of the world's richest rain–forests and largest reserves of biological life (Myers, 1988; Ramesh and Pascal, 1997). The vegetational diversity and floristic richness of the Western Ghats is remarkable and provide some of the best representatives of non-equatorial tropical evergreen forest in the world (Pascal, 1988 and 1991). Of the 15,000 higher plants recorded in India, over 4000 species are found in the Western Ghats and, of these, 1800 species are endemic to this area (International Union for Conservation of Nature and Natural Resources (IUCN), 1990). Over the past five decades, activities such as illicit cutting, land encroachment for agricultural expansion and settlements, reservoir flooding, logging and over-exploitation have drastically disturbed and reduced the forest at an alarming rate (World Conservation Monitoring Centre report WCMC, 1992). As a result, the Western Ghats region is considered as one of the endangered 'hot spots' of the earth by IUCN (1990). The economic and biological importance of these forests and the threats to their very existence, due to unorganised exploitation of forest resources, emphasises the need for improved planning and management.

1.3. Decision Support Systems (DSS)

Planning and management decisions concerning forest resources require the integration of large volumes of disparate information from numerous sources. They further demand the coupling of this information with efficient tools for assessment and evaluation in order to permit broad, interactive participation in the planning, assessment and decision-making processes. Successful production of such tools requires integration of spatial, non-spatial, socio-political, economic and expert opinion. It seems apparent that no single method or technique can address all of these requirements credibly and satisfactorily (Fedra, 1995). However, modern technologies such as Spatial Decision Support Systems (SDSS), which are an integration of many sub-systems, including Geographical Information Systems (GIS), analytical models, a user interface, data base management, and Knowledge Based System (KBS) seem to have the necessary power and flexibility (Fedra, 1991; Zhu and Healey, 1992; Rais et al., 1997; Wright, 1999).

The present study aims to develop a Range Management Decision Support System (RAMDSS) by combining Remote Sensing (RS), GIS, KBS, and analytical modelling to provide forest planner in the Western Ghats of India with an interactive and flexible spatial decision-making tool. This will be carried out by means of a case study from the Banavasi Range of the Western Ghats. The study will analyse the present planning problems in the study area and how they can be solved using DSS. In order to develop an appropriate DSS, the user requirements and data from different sources from the study area will be collected and analysed. Finally, an appropriate prototype DSS will be developed and tested with application example.

1.4. Aim and Research questions

To develop a RAnge Management Decision Support System (RAMDSS), that can assist the forest manager in improving forest planning in the Banavasi Range of the Western Ghats, India.

In order to achieve this aim, it is necessary to explore a number of related research questions:

Question #1: Why is improved forest planning and management required?

Objective #1.1. To examine the present methods and models of forest planning and management

Objective #1.2. To pin point the problems of the present systems

Objective #1.3. To develop new approaches for better planning

Question #2. What is required to develop a Decision Support System (DSS) for forest planners ?

Objective #2.1. To study the existing tools and understand the merits and limitations of each technique.

Objective #2.2. To develop an integrated system which can help to take effective planning and management decisions.

1.5. The structure of the thesis

The thesis is organised as follows:

Chapter II outlines the key elements of the world forest crisis and considers the urgent need for better tropical forest planning and management. It also explores the present planning tools, with their advantages and limitations. Finally, it concludes with how the procedures can be improved with a Decision Support System.

Chapter III describes the need for the development of Decision Support Systems (DSS) (including the Spatial Decision Support System) for forest planning. The second section starts with DSS definitions, characteristics and components required for the successful development of DSS. It also explains in detail the different development tools such as remote sensing, visualisation, Geographical Information Systems (GIS), and Knowledge Based System (KBS). The final section summarises DSS applications and examines the need for an integrated DSS approach to forest planning and management.

Chapter IV is concerned with a description and outline of the study area. This chapter briefly describes the Indian forest situation including the study area i.e. the *Western Ghats*. It also evaluates the forest policy and present planning strategies within the forest departments of India. The final section considers the selection of a case study area and the development of a prototype system.

Chapter V outlines the materials and methods used for the development of DSS. The different life cycles used in the development of software are examined, together with issues concerning the selection of an appropriate software lifecycle for this project. The chapter continues with the first stage of the software development cycle i.e. collection of user requirements for the development of the prototype system.

Chapter VI presents the conceptual design and implementation of the prototype RAMDSS. The data flow diagram is used to explain the conceptual design of the prototype. The second section evaluates the different tools required for the project and how they can be implemented.

Chapter VII is devoted to Data collection and processing. The first section explains the data collection from spatial, non-spatial and qualitative sources. The second part describes the processing of data using different software packages and also management of these data in the project.

Chapter VIII consists of an evaluation of the tools developed in the previous three chapters. An evaluation is made of the way planners can use the system for effective planning in the study area. The system is explained with an application example taken from the study area i.e. the Banavasi Range of the Western Ghats.

Chapter IX deals with discussion. The purpose of this chapter is to analyse the system developed in this study and evaluates how it fulfils the requirement of full DSS. This chapter also examines the limitations of the RAMDSS, and makes recommendations for future research. Finally it summarises the thesis with a brief conclusion.

Chapter 2: Problems statement

This chapter outlines the key elements of the world forest crisis and assesses the possible solutions to the problems raised. The first section deals with deforestation and evaluates the relevant statistics. The second section examines the need for better tropical forest planning and management in order to overcome difficulties resulting from traditional forest planning methods. The final section explores the different planning tools, which can be implemented and the need for an integrated approach through a decision support system to improve management of tropical forests.

2.1. Present problems in the world forests

> *"At the present time, the world's forests face two potentially devastating threats: a loss of total area of forest in large parts of the tropical and subtropical world and rapid decline in the quality of forest in much of the temperate and boreal regions"*
>
> *Dudley et al. (1996).*

One of the most critical environmental issues today is forest disturbance. Disturbance in the forest involves deforestation, forest fragmentation, a decline in forest productivity, a loss of biodiversity and the undermining of forest-dependent communities (Evans, 1996; FAO, 1997; World Resources Institute (WRI), 1998). Nearly 10,000 years ago, the earth boasted a rich mantle of forest and open woodland covering some 6200 m.ha (Postel and Heise, 1988), but due to forest disturbances this has been reduced to 4342 m.ha (FAO, 1997). The problems of deforestation and degradation in the tropics are especially serious.

It is well known that tropical forests offer a very wide range of highly valuable services which include important watershed and climate control functions, notably regulation of rainfall, absorption of the sun's rays and storage of sizable share of the world's carbon. In addition, they are the most biodiverse biomes on earth: the richest, oldest, most productive and most complex ecosystems on earth. Moist tropical forest contains at least fifty percent of all the earth's species and provides essential foods, clothing and implements for indigenous forest people.

Unfortunately, despite the importance of tropical forests they are being cut down at a rate of 40 percent faster today than they were 10 years ago (Lyke and Fletcher, 1992). The global forest cover in 1995 was estimated to be 4342 m.ha or 26.6 percent of the total land area of the world (Greenland and Antarctic excepted), of which tropical forest accounted for 58.9 percent of the total forest cover (FAO, 1997), (Figure 2.1).

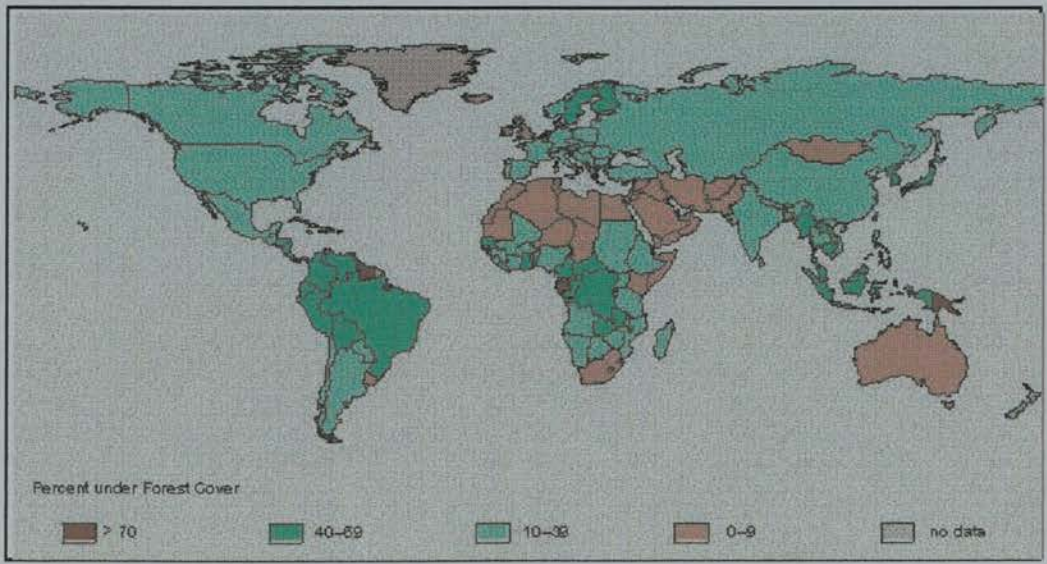


Figure 2.1. Current distribution of world forests (Source: FAO, 1997)

Tropical forest shrank by approximately 145,000 sq.km. per year in the early nineties. Of that amount, about 80,000 sq. km. fell to slash-and-burn agriculture. Another 10,000 sq. km. was destroyed in the search for fuelwood. Forest clearing for cattle ranching, mostly in Brazil and Central America, took another 15,000 sq.km. per year. Unduly destructive logging methods, primarily in South East Asia, took another 25,000 sq.km. annually. Large dams, mining and road building projects removed a further 10,000 sq.km., whilst forest clearing for tea, rubber and oilpalm plantations took about 5,000 sq.km (Ahmed, 1997). The detailed problems, statistics and processes of tropical forest deforestation are well discussed in the literature (Lanly and Clement, 1979; Guppy, 1984; Myers, 1980; Sedjo, 1987; Poore and Sayer, 1990; Sayer and Whitemore, 1991; WCMC, 1992; FAO, 1997; WRI, 1998). The detailed changes of forest area (from 1985 to 1995) in the tropics are given in Table 2.1. The table also clearly shows that degradation of forest is very high in Latin America and Asia. The comparison of overall statistics from 1985-90 with 1990-95 reveals that there is a slight decrease in the rate of deforestation in the developing world (Table 2.1).

Table 2.1. The changing status of forest in tropical countries

Regions	Annual forest area change					
	1990-1995				1985-1990	
	Natural forests		Total forests (b)		Natural forests (a)	Total forests (b)
	(m. ha)	(percentage of 1990 area)	(m. ha)	(percentage of 1990 area)	(m. ha)	(m. ha)
Africa	-3.75	-0.71	-3.75	-0.71	-4.28	- 4.12
Asia-Oceania (developing)	-4.17	-0.89	-3.47	-0.67	-4.41	-1.70
Latin America and Caribbean	-5.81	-0.61	-5.81	-0.60	-6.77	-6.44
developing world	-13.73	-0.70	-13.03	-0.65	-15.46	-12.26

a The negative figures denote deforestation.
b The difference between an increase in area due to plantation establishment and a decrease in area due to deforestation.

(Source: FAO, 1997)

Recent information on the nature and causes of change in forest cover of tropical areas suggests that the expansion of subsistence agriculture in Africa and Asia and large economic development programmes involving resettlement, agriculture and infrastructure in Latin America and Asia, are key factors behind forest cover change

(FAO, 1997). Some authors argue that the underlying causes of deforestation in developing countries are poverty, skewed land distribution (due to historical patterns of land settlements, ownership and commercial agriculture development), low agricultural productivity and rapid population growth. These factors have led into increasingly severe pressure on forest lands (Lyke and Fletcher, 1992).

The continued forest loss has resulted in a number of repercussions, which include erosion, loss of biological diversity, damage to wildlife habitats, degradation of the quality of life and global warming. These problems reduce the options for development at local, regional and global levels. The inevitability of human population increase and the severity of the related impacts on natural resources, including natural forest, require urgent and consistent action for conserving and sustaining forest resources, especially the tropical forests, through proper planning and management (FAO, 1990; Rio Earth Summit, 1992). In order to implement proper planning it is necessary to understand the different meanings, goals, planning levels, tools and methods involved in the planning process (Rio Earth Summit, 1992). The next section explains these issues in greater detail.

2.2. Forest planning and management

Planning and management are closely related. Planning usually refers to an analysis of the present situation and anticipated future needs in order to prepare a plan to meet these demands. On the other hand, management is the set of operations by means of which a plan is implemented (Young, 1991). Planning is especially important where resources are severely constrained and it is essential that whatever limited means are available, they are applied as efficiently as possible to the solution of high priority problems (FAO, 1991). Planning is carried out at various scales and for a wide range of purposes and hence the procedures to be followed will vary from one case to another. The planning hierarchy of scale includes continental (broad planning at the level of international agencies and governments); national or state; district and village level (this is the level at which planning is implemented and day-to-day management operations are undertaken). Young, (1991) classified the planning hierarchy based on method of implementation such as strategic, tactical and operational.

Young (1991), outlined the major goals of forest planning which include a numberof factors: *economic* (increased productivity of timber, foreign exchange and national self sufficiency); *social* (increased productive employment, net income to small landowners and community stability) *environmental* (protection of endangered species, preservation of threatened ecosystem and bio-diversity, development of environmentally sustainable production); and *scientific* (increase basic understanding of tropical forest ecology). In order to achieve these goals there is need for different tools and this issue is discussed in the next section.

2.2.1. Planning tools for forest management

The management plan and working plan are the major tools of traditional planning in forestry. A management plan deals with matters such as administrative set-up, supervision and its control. For example the number of woodsman, lorry drivers required and their housing, equipment and finance. The general purpose of management plans is to bring together in one document the guiding principles and measures for development and control of the business of timber production and yield for a given working area. In addition, the management plan contains many features that do not form part of a plan of operations. In general, the working plan is a tool, designed to be used in the daily business of the forest to which it applies (Myers, 1980). It requires technically good judgement and common sense. A working plan is also and fundamentally, a plan for ordering the silvicultural treatment of the wood and bringing system and a foresight into their cultivation. The main difference between these two plans is that a management plan is used for administrative purposes whereas the working plan is used for operational purposes. The following section discusses working plans in detail considering their nature and limitations.

The conventional planning instrument of forestry i.e. the working plan, was largely developed in Germany in the nineteenth century. Working plans were originally divided into two parts, part one consisting of a description of the forest and part two involving prescriptions for a fixed period of time ahead. For example in India, the practice is for a working plan to have a life of 10 years. The working plan precisely identifies the species of timber to be cut, the sequence in which cutting will take place, the methods that will be used to build and maintain logging roads, the harvesting equipment and techniques to be applied, fire protection and reforestation plans and the measures that will prevent, minimise, mitigate, or compensate for environmental disturbances. However, the present day working plans have many shortcomings: firstly, there are no clear statements of the criteria with which to judge the relative success of different courses of action; secondly, there are no provisions for planning at levels other than that of the total forest for assessing the complex interactions that occur with strategic planning; and thirdly, the traditional working plans have little flexibility. In addition most of the plans for the timber production (Johnston et al., 1967), concentrate only on timber harvesting and public participation is not included in the planning process (Project Process Development Programme 49 report, 1998).

In the 1950's and 1960's, planners recognised the concept of managing the forest for multiple-use purposes (FAO, 1985; Franklin, 1997). The primary objective was to make the greatest number of forest resources available to the greatest number of people (Owen and Chiras, 1990), or meeting two or more major objectives simultaneously. However, the concept of multiple forest use does not include the ecological knowledge to the practical integrated management approach and emphasises output of goods and services, rather than stewardship of the ecosystem (Franklin, 1997).

In order to overcome the limitations of the traditional working plan and to include the importance of social, political and economic criteria in planning, the concept of Sustainable Forest Management (SFM) has recently emerged as a new conceptual framework. This involves management which ensures long-term forest health and productivity whilst providing continued social and economic benefits (Evans, 1996). FAO (1991) defined the objectives of SFM as:

"Sustainable forest management aims to ensure that the values derived from the forest meet the present needs while at the same time ensuring their continued availability and contribution to requirements of long term development" .

The Rio Earth Summit (1992) Centre for International Forestry Research (CIFOR), (1995); FAO (1995 and 1997); United Nations Conference on Environment and Development (UNCED) and work in many countries, organisations, conferences and international initiatives have highlighted and discussed the urgent need for sustainable forest management through improved forest planning. The "Helsinki Process" (MCPFE (Ministerial Conference on the Protection of Forests in Europe), 1993), the "Montreal Process", the "Tarapoto Proposal" and "The United Nations Environmental Programme (UNEP) / FAO Expert Meeting" are some of the initiatives set up to develop such criteria for the development of SFM. Each of these processes has proposed criteria and indicators by which sustainable forest management can be achieved. The above meetings all stressed and identified important criteria for sustainable forest management. These are summarised below:

- Conservation of biological diversity;
- Maintenance of productive capacity of forest ecosystems;
- Maintenance of the health and vitality of forest ecosystems;
- Conservation and maintenance of soil and water resources and the protective and productive functions of forests;
- Maintenance of the forest contribution to global carbon cycles;
- Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies;
- Legal, institutional and economic frameworks for forest conservation and sustainable management. (Source: FAO, 1997)

In order to develop a Sustainable Forest Management Plan with the above criteria, timely collection, compilation and analysis of data/information, including baseline surveys is required and these include:

- Carrying out surveys and implementing plans;
- Consolidating and updating land use and forest inventory and management data;
- Collection/acquisation of local/indigenous knowledge on trees and forests status
- Compiling and analysing research data on environment, ecological, biological, social and economic data;
- Establishing linkages with other data/information sources (Rio Earth Summit, 1992).

With this diverse information, the forest manager needs to know how to solve problems such as "which areas of land should be under forestry?" or "which zones should be allotted to other kinds of land use? " or "which parts of the forest land should be reserved purely for protection and conservation purposes?" "Which should be the areas used for production?" etc. (FAO, 1984). Answering these questions involves complex decision-making processes with the long-term objectives of better control of forest exploitation utilising diverse sources of information.

2.3. Need for integrated planning support system

Sustainability and more holistic planning and management requires being able to manage our forest resources in ways which will ensure their integrity, productive capacity, resilience and bio-diversity and satisfy our economic and environmental values (Bonnell and Pittman, 1994). This difficult task demands an integrated approach to provide efficient planning. The Agenda 21, Chapter 10, of Rio Earth Summit (1992), the programme of action for sustainable development mentioned the need for an "integrated approach to the planning and management of land resources" in order to combine the diverse source of information. Rais et al. (1997) contributions to and several conferences such as the "International Conference on Geo-information for Sustainable Land Management (SLM)", (held in The Netherlands 1997), GIS `97 (Eleventh Annual Symposium on Geographic Information Systems: Integrating Spatial Information Technologies for Tomorrow) and "The Application of Scientific Knowledge to Decision-making In Managing

Forest Ecosystems" (to be held in Asheville, USA (1999), also highlight the importance of the integration of diverse source of information into the decision-making process.

The above process is complex, multi-disciplinary and requires solutions that can integrate the data and model knowledge across a wide spectrum of research areas (Loh et al., 1991). This in turn has led to the development of computerised systems to provide decision support services, in order to assist the manager at various levels of decision-making (Bunce and Heal, 1984; Rais et al., 1997; Sugumaran et al., 1998a).

DSS is a software application that provides an integrated environment in which a collection of tools can be efficiently used together to manage a larger portion of the overall decision-making process (Reynolds, 1996). The integration of techniques which include data base management, geographical information systems, expert or knowledge based systems, graphical user interfaces, visualisation, hypertext, seem to have the necessary power and flexibility to support environmental planning and management in practical applications (Fedra, 1991 and 1994). Each tool is discussed in the following paragraphs.

Satellite remote sensing represents a unique and important state-of-the-art tool for mapping, monitoring and updating the degradation of tropical ecosystems. It has advantages of repetitiveness for monitoring, cost effectiveness, real time data acquisition and a synoptic view over the traditional forms of data collection (Gills and Leckie, 1996). A further important tool is a Geographical Information System (GIS), which can help improve the quality of decision-making through its increasing capacity of analysis, display and management of both spatial and non-spatial data. Additionally, the technique of visualisation is a form of communication, which has the ability to form an abstraction of the real world into a graphical representation, which is comprehensible to a wide range of people (Loh et al., 1991). Finally, Expert Systems (ES) or Knowledge Based Systems (KBS) that can solve problems within a narrow field of expertise, typically act as a communication medium between the expert and non-expert user (Hayes-Roth et al., 1983).

In order to take advantage of the above systems they are best integrated into a single system for improved forest planning (Bonnell and Pittman, 1994). Recently, several authors have suggested that the integration of data base management systems, GIS, remote sensing and image processing, visualisation, Expert Systems and computer graphics provides some of the most effective tools for decision support in natural resources management (Rio Earth Summit, 1992; Fedra, 1995; Rais, et al., 1997; FAO, 1997). All the systems mentioned above however, attempt to address only part of the complete decision process. Therefore, in order to achieve improved decision-making, all the tools and models have to be combined in an integrated information processing and decision-making procedure.

The need for an integrated system approach in environmental and resource management problems has been discussed and advocated for a considerable time (Holcomb Research Institute, 1976; De Wispelaere et al., 1986; Loh et al., 1988; Fedra and Reitsma, 1990; Fedra, 1991; Heatwole, 1993). Theoretical possibilities have also been extensively and adequately covered (Goodchild and Densham, 1990; Densham, 1991; Moon, 1992; NCGIA, 1992; Ray et al., 1999). There are many case studies undertaken to develop specific DSS, for example, silvicultural practices (Riesinger and Davis, 1987; Bulger and Hunt, 1991; Rauscher et al., 1995), land use planning (Chandra and Goran, 1986; Morse, 1987; Williams et al., 1995; Zhu, 1995; Wood and Dewhurst, 1998) and forest protection (MacLean, 1995; Baijal, 1996; MacLean et al., 1997; Wybo, 1998). However, there are very few studies which have been undertaken to develop a DSS which addresses multiple goals, as is implicit in sustainable forest management. Therefore, the integration of these technologies for developing integrated decision support systems is an obvious and promising idea.

2.4. Summary

This chapter summarises the problems resulting from land pressures such as deforestation and their effects on the environment and explains the urgent need for better planning and management of existing forest resources. The planning and long-term management of these resources requires diverse and multi-disciplinary approaches which in turn, need integrated resource assessment on which to base operational decisions. The value of developing an integrated decision support system using tools such as remote sensing, GIS, Expert Systems and visualisation in a combined approach has great potential to provide the forest manger with the information and analytical procedures to solve the above problems. The current state of research in forest management using remote sensing, GIS and Expert Systems and how to build an effective DSS for forest planning will be assessed in the next chapter.

Chapter 3: Decision Support System (DSS) for forest planning and management

This chapter offers a brief assessment of current issues in forest planning and a need for an integrated DSS. Section 3.2 deals with the *Decision Support System* (DSS) (including the Spatial Decision Support System) definitions, characteristics and their development. Section 3.3 demonstrates how to build a successful SDSS and considers the tools or techniques required to achieving such objectives. The potential tools and techniques:- such as remote sensing, GIS, visualisation, Knowledge Based System (KBS) are discussed in detail. The final section demonstrates the need for an integration of these tools in order to develop an efficient DSS for forest planning and management.

3.1. Forest planning and management

The continued reduction in forest has caused the planner to make better or improved planning and management of the existing forest. Forest planning and management are extremely complex and require information on a wide variety of resources for example on forest inventory, socio-economic and other information on physical parameters such as soil, geology, geomorphology and land cover. Present day methods such as working plans, are not able to handle these issues very well because of the information required from different sources, less flexibility and not available in time (see chapter 2). In order to handle the variety of data, to be able to solve more critical and complex environmental and resource management problems and taking timely decisions, there is urgent need for better tools in an integrated approach.

Integrated resource management (IRM) can be broadly defined as managing the forest resource for a variety of objectives including fibre production, wildlife habitat preservation, recreation and wilderness conservation (Anonymous, 1990). This form of planning requires the establishment of a process that ensures resource management agencies consult one another and various interested parties, to the extent that no one forest value is developed to the exclusion of other opportunities. This process is based on the management philosophy that there should be shared decision- making, a high degree of co-ordination and cooperation and a recognition of the legitimacy of other interests, with the ultimate aim of resolving any anticipated conflict (Anonymous, 1983; Lang, 1986; Mitchell, 1986; Kao et al., 1993). Within the integrated resource management paradigm of today, the requirements for detailed up-to-date and reliable information and analyses of these data have increased dramatically. In addition, because of the complex nature of forest planning, there is a need for the system, which can handle all these issues. As mentioned in the previous chapter, one promising approach to these problems is to develop suitable decision support systems (DSS) at various levels of decision-making in order to support complex forest planning and management (Bunce and Heal 1984; Fedra, 1995; Rais et al., 1997). The following section explains the definition, characteristics and development of DSS.

3.2. Decision Support Systems (DSS)

3.2.1. Definitions

Many definitions for DSS are given in research or review papers. One common feature in these definitions is that they all require the involvement of computers to produce information for the decision-maker. Simonovic (1994) describes decision support systems as follows: "DSS allows the decision-maker to combine personal judgement with computer output". Sol (1983) provides an alternative definition:

"Decision Support Systems are described as analytical tools which can be used to assist the decision maker in assessing the inter-relationships and potential effects of a policy or decision". Densham and Rushton (1988) describe DSS as a tool to solve semi-structured problems. In general, it can be represented simply a tool, which can assist the decision-maker in making more informed decisions.

The decision supporting process in DSS involves both a descriptive information system as well as the more formal, normative, prescriptive optimisation. The important steps involved in the decision-making process are given in Figure 3.1. Any decision-making process involves firstly identifying the problem and then generating alternative courses of action, followed by evaluation of the alternatives, selection of the best strategy, implementation and finally evaluation of the decision (Figure 3.1). The detailed characteristics of the decision-making process in DSS follow in the next section.

3.2.2. DSS characteristics

DSS can be crucial in supporting the decisions of users and in gaining new insights into the structure of particular problems. This is achieved by generating different decision scenarios and by utilising the skills of users so that they can recognise meaningful alternatives and strategies throughout the problem-solving process (Wherrett, 1996), (Figure 3.1). More specifically, the users should be able to contribute to reducing the uncertainty faced by managers. Decision support systems must also provide the integration of information and feedback loops in order to support the exploratory nature of the process of scientific discovery (van Voris et al., 1993) (Figure 3.1).

In addition, DSS is a system to support decision-making, along with a report generator to portray this information to the decision-maker and a user interface to make the system easy to use. The above characteristics can cater for a range of purposes, for example spatially based decisions such as site selection, land use planning or for non-spatial based decisions such as financial (banking or business) applications. If the DSS is specifically used for supporting complex decisions based on some kind of spatially distributed information, then it is called a *Spatial Decision Support System* (SDSS) (Djokic, 1993).

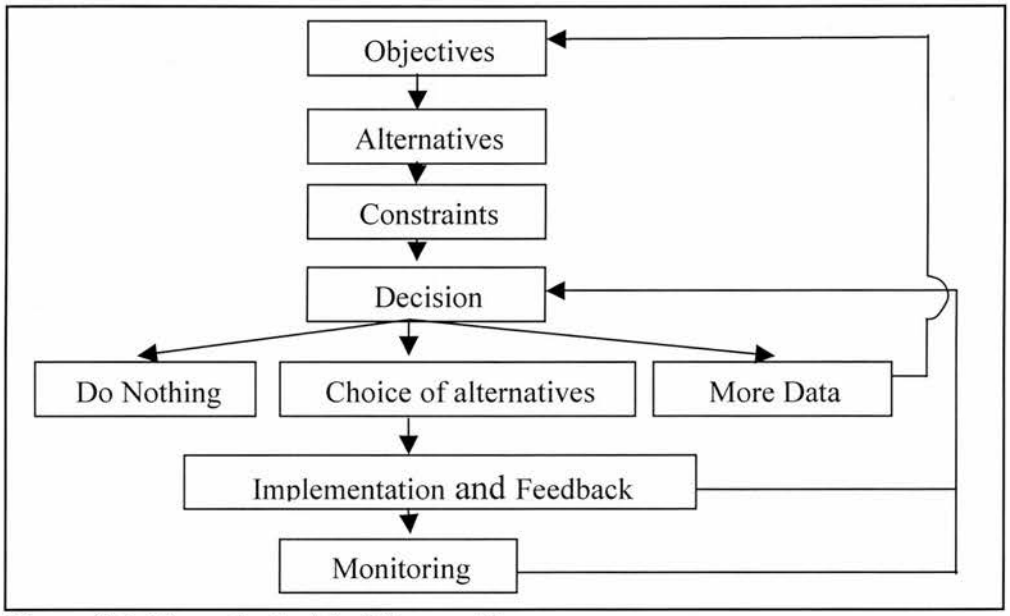


Figure 3.1. Flow chart of decision-making process

The concept of spatial decision support systems (SDSS) represents an effort to address complex spatial problem solving and assist in spatial decision-making. Forest land use planning and management is one of the most suitable areas for the application of an SDSS. SDSSs have developed in parallel to the DSS and have the same characteristics but, in addition, they have a spatial element. Several authors described the characteristics of a DSS and SDSS (Geoffrion, 1983; Densham, 1991; Host et al., 1992; NCGIA, 1995; van Voris et al., 1993; Church et al., 1994; Mann, 1996). The following paragraph summarises the characteristics of both DSS and SDSS outlined in the above references:-

1. to provide mechanisms for the input of spatial as well as relevant attribute data (Densham, 1991);
2. to be able to update easily (Host et al., 1992);

3. to be able to manage large spatial and non-spatial data sets including storing, retrieving and analysing the data (Mann, 1996);
4. to support simple visualisation capability (Church et al., 1994);
5. to allow representation of spatial relations and structures; including analytical techniques for spatial analysis (Geoffrion, 1983);
6. to enable the user to combine models and data in a flexible manner (Densham, 1991);
7. to help the user explore the solution space (i.e. the options available to them) by using the models in the system to generate a series of feasible alternatives (Geoffrion, 1983);
8. to redesign or to solve semi-structured problems, i.e. where objectives cannot be fully or precisely defined (Geoffrion, 1983);
9. to provide an interface that is both powerful and easy to use (Geoffrion, 1983);
10. to provide decision-making knowledge derived from domain experts (Densham, 1991);
11. to produce output in a variety of forms, including maps or automatic report generation (Densham, 1991); and
12. to access the existing knowledge about the system (Host et al., 1992).

In order to build a suitable SDSS for forest planning with the above characteristics requires different technologies and techniques. The components required for developing a suitable SDSS for forest planning and management are examined next.

3.3. Building a SDSS for forest resource management

The ultimate objective of the development of a computer based decision support system for any natural resources management is, or should be, to improve planning and decision-making processes by providing useful and scientifically sound information (Fedra, 1994). Decision Support Systems (DSS) have been developed for many different applications since the late 1970s (Haseman, 1977). For example, DSS has been designed for forest protection, which includes fire and disease

(Marshall and Mccullogh, 1995: Carrega, 1997; Wybo, 1998), and for forest land use planning (Chandra and Goran, 1986; Zhu, 1995). In the last few years several theoretical conceptualisation have been also suggested for the building of an effective integrated SDSS (Bigdoli, 1989; Goodchild and Densham, 1990; Moon, 1992; Mallach, 1994; Holsapple and Whinston, 1996; Dhar and Stein, 1997).

Many researchers have used different components for the efficient development of SDSS. For example, the technique of remote sensing has been employed for rapid updating of spatial data (Crain, 1992; Fedra, 1994; Rajan, 1995; Gumbricht et al., 1996; Badji and Dautrebande, 1997; Moran et al., 1997), a relational database has been designed to maintain the attribute data sets: GIS for spatial data analysis (Aspinall et al., 1992; Rais et al., 1997); and an expert systems or knowledge based systems to provide assistance for complex spatial problems (Goodchild and Densham, 1990; NCGIA, 1992; Zhu, 1995; Reynolds, 1996; Zhu et al., 1996). Armstrong and Densham (1990), have grouped these characteristics into five key components in order to develop a spatial decision support system: (1) a Data Base Management System (DBMS); (2) a Model Management System (MMS), including analysis procedures; (3) a display generator; (4) a report generator and (5) user interface. The next section explains in detail all the five key components involved in the development of SDSS.

3.3.1. Data Base Management System (DBMS)

A database is a collection of information about objects and their relationships to each other. For example, a database may consist of forest inventory data (Aronoff, 1989). A Database Management System consists of "a collection of programmes for restructuring, storing, updating and retrieving data" (Simon, 1996). Common Data Base Management Systems includes relational databases, which describe reality through a set of tables (relations) linked by keys (common fields or attributes) and the geographic databases associated with the geographic information system. The DBMS and Geographical Information System (GIS) provides a complete service for collecting, storing, retrieving and manipulating both spatial and non-spatial data (SDSS characteristics 1, 2 and 3). Each section will be discussed in greater detail; the first section demonstrates what data are required and how they will be collected in order to develop the SDSS.

3.3.1.1. The data collection for forest planning and management

Databases required for developing a spatial decision support system specifically for forest planning and management may include a variety of data because of the complex processes involved in forest planning including issues of an ecological, environmental, social and economic nature. These processes require up-to-date spatial and non-spatial data, acquisition of many kinds of specialist knowledge and techniques from various related disciplines (Sharifi, 1992; Puttee, 1989; Funnpheng et al., 1994). As an example, Susilawati and Weir (1990) quoted the example of spatially and non-spatially referenced information sources necessary for forest planning and management, which are considered to be:-

- *Administrative boundaries*
  - Cadastral boundaries
  - forest administrative boundaries
  - compartment and sub-compartments
  - timber concession boundaries
- *Terrain features*
  - elevation
  - slope
  - aspect
  - drainage
- *Infrastructure*
  - roads, tracks etc.
  - building and other structures
  - power lines, pipelines
- *Soil and under-storey vegetation*
- *Forest stand characteristic*
  - age
  - species composition
  - yield class
  - density
- *Management activities*
  - realised and planned silvicultural treatment
  - land usezoning
  - fire control and damage control

Traditional methods of collecting and updating these data are based on intensive ground surveys or through aerial photograph interpretation. Ground surveys range from chain and compass to Global Positioning Systems (GPS). However, these methods have severe limitations, which include the slowness of obtaining the data, the costs and difficulties in updating the data and intensive labour demands. Recently, satellite remote sensing technology has been proven to be a valuable tool, for improving the forest inventory data and stand management and for rapid update (SDSS requirement 2) (Gumbricht et al., 1996; Llewellyn et al., 1996). Satellite remote sensing provides a means of collecting area information repeatedly, on a regional or global scale, particularly in remote areas which are difficult to access by any other means. They are also cost effective and valuable in terms of real time data acquisition compared to traditional methods. Several authors also explained the importance of incorporating RS into SDSS for several other types of application (Crain, 1992; Schultink, 1992; Fedra, 1994 and 1995; Rajan, 1995; Gumbricht et al., 1996; Llewellyn et al., 1996; Badji and Dautrebande, 1997; Moran et al., 1997). The following section discusses how satellite remote sensing can contribute in collecting real time data and to assist in SDSS for forestry planning.

3.3.1.2. Remote sensing (RS) for forestry application

The conversion and destruction of the tropical forests in Asia, Africa and South-America proceeds mostly uncontrolled and at a dramatically increasing rate. However, accurate information on existing global tropical rain forest resources and the monitoring of their development together with information about the current land use, extent location and conditions of forest is still not known precisely. These data are prerequisite for any decision concerning forest management (Gills and Leckie, 1996). During the past four decades, considerable changes have taken place in tropical forests because of factors such as forest fire, encroachment, deforestation and disease. These changes in turn demand a regularly updated forest inventory and frequent monitoring of land cover changes. Such data collection and management assists forest managers to assess the forest extent, plant growth and to prescribe the actions necessary to achieve better forest decision management (Rajan, 1995; Pitt et al., 1997).

Inventory updating may be defined as the process of detecting, collecting and adding to the inventory for operational management and strategic level planning and for reporting purposes. As the demand for detailed and accurate data has increased it has become questionable whether the currently most extensively applied forest inventory method based on compartments and visual assessment is effective (Gills and Leckie, 1996). In this connection, recent satellite remote sensing is a possible solution to the increasing information needs, as it provides a means of collecting areal information rapidly and repeatedly, on a regional or global scale. The following section discusses the significance of some of the important applications of remote sensing in forestry data acquisition.

3.3.1.3. Forest mapping and monitoring

The role of RS for forest mapping and monitoring is well documented in the literature. Such mapping and monitoring is essential for judicious management since it is a direct indication of the ecology of the area (Jadhav et al., 1994). The launch of ERTS-1 (Landsat 1) in 1972, opened a new era for understanding natural resources and provided a methodology for better management. Mapping and monitoring procedures have included land cover, forest type and density, deforestation, forest fires, forest disease etc. at different spatial scales.

Two kinds of satellites are used for studying forest or any natural resources. Environmental satellites, such as Europe's Meteosat or the United States' NOAA-AVHRR, offer more frequent but less detailed pictures of areas as large as countries or continents. At the global level, a number of satellite systems have been dedicated to monitoring the environment, such as NOAA AVHRR, which has a twice daily over-pass and can be freely down loaded by low-cost ground receiving stations. The FAO's comprehensive assessment of the world's forest resources, published in 1995, drew heavily upon remote sensing source data and other national statistics. In another typical study (Malingreau et al., 1989) AVHRR data was employed for tropical forest monitoring at global scales. Such activities form part of the Global Environment Monitoring System (GEMS).

A second group of sensors used are the earth resources satellites which have more detailed ground resolution (between 5 and 80 meters) suitable for the thematic mapping monitoring. The FAO has drawn on data from earth resources satellites for thematic mapping projects in over 70 countries (FAO, 1991). In order to use these satellites at regional and local level, several hyper-satellite remote sensing sensors have been launched from various nations, such as the American Multi Spectral Sensor (MSS) and Landsat, Thematic Mapper (TM), the Indian Remote Sensing (IRS) satellite system and the French SPOT satellites. These sensors have been used for the mapping and monitoring of forest types and crown density (etc.) The detailed applications are examined in the following paragraphs.

The first and important application of the satellite remote sensing is the mapping of forest resources. Mapping forest type and forest density are common uses of satellite remote sensing. Forest type is defined as a unit of vegetation which possesses (broad) characteristics in physiognomy and structure sufficiently pronounced to permit its differentiation from other units (Champion and Seth, 1968). There have been a number of studies that have been undertaken to delineate the existing forest cover using different sensors like Landsat MSS, TM, LISS-II, LISS-III and SPOT. (Mace and Bonnicksen, 1982; Skidmore and Turner, 1988; Bodanskii et al., 1990; Kachhwaha, 1993; White et al., 1995; Roy et al., 1996). On the other hand, forest density (crown density) refers to per cent canopy cover with respect to ground area exposed. Several authors have developed satellite based forest density maps using different sensors (Jadhav et al., 1994; Zhu, 1994; Roy et al., 1996).

A second important use of satellite remote sensing is monitoring. This is the periodic assessment of changes in land use/ land cover (Singh, 1989). Understanding the changes in forest cover is very important because forest area may change rapidly. Many countries are now monitoring their forest using the remote sensing technique.

For example India is monitoring forest status every two years using their indigenous satellites, the Indian Remote Sensing (IRS) series. Forest fire, biomass and land cover change are some of the applications examples for monitoring. Thus, monitoring of forest resources with hyper-satellite has proved to be valuable in efficient planning. The following paragraphs show some of the applications using hyper satellites for monitoring the forest resources.

Forest fire is one of the major causes of deforestation. The effectiveness of monitoring forest fire using high resolution satellite data such as Landsat TM, SPOT and IRS has been well proven (Chung and Le, 1984; Flannigan and Vonderhaar, 1986; Wilson et al., 1994; Koffi et al., 1995; White et al., 1996; Kimothi and Jadhav, 1998). In addition, low resolution data such as AVHRR has also used to study the larger area by several others (Flannigan and Vonderhaar, 1986; Malingreau et al., 1989; French et al., 1995; Harris, 1996; Pereira, 1999; Roy et al., 1999). Satellite remote sensing is used in India to give real time fire direction information to the forest manager during every summer, so that preventive measures can be taken (Jadhav et al., 1995).

Forest cover also changes due to factors such as encroachment from agriculture, and developmental activities such as dam construction or new road construction. These can also be monitored using satellite imagery. Such images have also helped the public decision-making process. For example, in India, judgement of the encroachment case in the court was resolved based on the map produced from the satellite data (Jadhav et al., 1996). Other examples of remote sensing data application include biomass estimation (Roy and Ravan, 1996) and disease monitoring (Dister et al., 1997; Hay 1997; Kitron and Kazmierczak, 1997). The following section discusses the limitations of the present satellite remote sensing technology.

3.3.1.4. Limitations of the present satellite remote sensing technology

Although developments have been broadly based across many divergent disciplines, there is still much work required to develop remotely sensed images for use in natural resource management. Problems such as the need for better spatial resolution, cloud free data, suitable season of the image, shadow effects, the improvement classification accuracy of the output and implementation work in an operational system are some of the areas to be developed (Beek, 1997).

Firstly, the important problem with the satellite image for forest studies includes differentiation of vegetation types specifically in the natural forest. Differentiating the forest type, particularly dry deciduous patches, is another problem with satellite data because of leaf fall. Some authors have suggested that multi-temporal satellite data can be a useful tool for solving this problem. Lathrop and Bognar (1994) explained that AVHRR imagery recorded after leaf fall appeared to enhance the discrimination of coniferous versus deciduous forests. Secondly, the problem of clouds. The major disadvantage of optical sensors is that cloud-free conditions are always required (Wegmüller et al., 1995). However, recently, substantial progress was made to overcome this problem by using SAR interferometric analysis of repeat-pass ERS-1 SAR data. Thus, suitable season and different vegetation physiognomy need to be considered before the acquisition of satellite images.

Thirdly, there are problems such as spatial and spectral resolution of the image. Presently the best available satellites have only a spatial resolution of 5 metres (panchromatic) and 20 metres (multi-spectral) and it is not possible to distinguish objects less than this resolution. These problems could be solved in the near future. Several countries have already started working to improve and solve the spatial resolution problem by launching hyper-satellites. Illustrative of this are two American companies, Space Imaging EOSAT and Earth-watch, who plan to launch satellites with pixel sizes of 1 m and 3 m respectively. In addition, a second satellite will be launched by Earth-watch in 1999 and will have a resolution of 85 cm. India and France are also planning to launch a satellite with 3 meter resolution. The above new satellites will solve some of these important problems such as spatial and spectral resolution, however, it may create other problems of data overload in the analysis stage.

Finally, there are problems related to improving the classification accuracy, which is an essential issue. The present system of automated classification yields accuracies that are unacceptably low for many land cover applications. This is a major reason why forest land mangers have been slow to adopt remotely sensed satellite data for operational use (Skidmore and Turner, 1988). Traditionally a statistical classifier, such as Maximum likelihood (ML), has been used to classify the land cover of the earth's surface. This statistical approach works by assigning a value to the class for which a unit of land cover is the most likely member, based on multi-variate spectral values (Yool, 1998). This approach gives marginally good classified accuracy ranging from 54-94 per cent for different sensors such as Landsat TM & MSS, IRS series and SPOT. Lately several authors have tried to improve the accuracy of such data using a combination of different techniques. Kent et al. (1988) have used topographic data such as slope and aspect, to improve the TM based land cover classification. But they have reported no significant increase in land cover classification. Similar results were achieved by Bolstad and Lillesand (1992), through a Rule-based approach by using the combination of soil texture and terrain position in the western Great Lakes region of US.

However, some authors have suggested that Artificial Neural Network (ANN) classifiers could replace the traditional maximum likelihood classifier, because this approach has the ability to classify without assuming a distribution (Kamata and Kawaguchi, 1995). ANN is based on large number of simple interconnected neurons or units, that work in parallel to categorise input into output classes (Hepner et al., 1990 and Foody et al., 1995). An extensive amount of work has been undertaken over the last few years in applying ANN to the classification of data from different sensors; in particular Landsat TM (Hepner et al., 1990; Civco, 1993; Kamata and Kawaguchi, 1995; Jarvis and Stuart, 1996; Zhang et al., 1997; Yool, 1998); SPOT (Kanellopoulos et al., 1992; Dreyer, 1993; Chen et al., 1997); SAR (Decator, 1990; Foody et al., 1995; Chen et al., 1996; Tseng and Chen, 1998), IRS LISS-II (Sugumaran et al., 1998b) and AVHRR (Key et al., 1989; Visa and Iivarinen, 1997). Most of the results suggested that an ANN classifier can improve the classification accuracy. A few researchers have suggested incorporating GIS and Experts System to increase remote sensing classification accuracies (Zhang et al., 1997; Chen et al., 1996). The integrated approach offers a better understanding and quantification of uncertainties in remote sensing studies (Stein et al., 1998).

3.3.1.5. Summary

Effective decision-making requires accurate and timely information. Satellite remote sensing is a very important tool, since it provides up-to-date information, which helps in taking timely decisions (SDSS requirement 2). However, problems such as suitable season of the image, cloud free data, required classification accuracy and scale have to be taken into consideration before using the satellite image.

After collecting data from either remote sensing or ground survey it has to be efficiently stored and maintained. In order to achieve these issues, the next section demonstrates the different tools required and how they can be used in the development of SDSS.

3.3.2. Data maintenance

Data maintenance includes storing, retrieving and analysing the collected data. It is an important stage in the development of the data base management system (SDSS requirement 3) because the data sources are usually large, heterogeneous in nature, at different scales, with different co-ordinate systems and different accuracies (Guptill, 1988). Relational Database Management Systems (RDBMS) and Geographical Information Systems (GIS) are specifically designed to deal with these problems. The

RDBMS can be used to store information for tabular formats whereas GIS are efficient for storing, retrieving and analysing and displaying spatial information (Aronoff, 1989). The subsequent sections deal with a short history, advantages and limitations of present GIS and how they contribute to successful development of SDSS.

3.3.2.1. The Geographical Information System

A GIS is a computer system designed to allow users to collect, manage and analyse large volumes of spatially referenced and associated attribute data (Guptill, 1988). In another definition, Chorley (1988) has defined GIS as, "a tool about aiding managers to carry out their jobs more efficiently and more particularly, about better decision-making". The history of GIS illustrates that in 1970's, a GIS was primarily a visualisation tool, whereas in 1980's it was linked to database management system and, now, with the advent of object-orientation GIS, can be coupled with a spatial-feature system for spatial manipulation (Reynolds, 1996). Present GIS fulfils several SDSS characteristics (SDSS characteristics 1, 2, 3, 4 and 5) and has advantages such as:

- The capacity to store large amount of varied information (including remote sensing data) for integrated analysis (Lillesand et al., 1989);
- The capability to bring various forms of information from many different sources together and relate them on a common spatial basis (Mcabee, 1991);
- To help in analysing simple 'where' and 'how much' questions and to the more complex 'what if' types (Aspinall et al., 1992);
- The flexibility and speed with which data can be assessed and interpreted compares favourably with other conventional methods (Aspinall et al., 1992);
- The ability to analyse which is unavailable with more traditional methods of map manipulation;
- The provision of various display facilities gives better visualisation than alternate methods (Zhu, 1995).

The above characteristics clearly show that GIS can contribute very much to the successful development of SDSS because of its storage and retrieval (SDSS characteristic 3) and analytical capabilities (SDSS characteristic 5), together with simple display facilities (SDSS characteristics number 4 and 11). Realising the importance of GIS, several case studies have been undertaken in the forestry sector over the last two decades. An outline of the GIS role in forestry is discussed below.

3.3.2.2 Application of GIS in forestry

The importance of GIS in the forestry sector, especially in forest planning, is frequently mentioned in the literature (Tomlin and Boyle, 1981; Burrough, 1988; Jordan and Erdle, 1989; Read and Raber, 1989; Baskent et al., 1992; Smith et al., 1994). Aspinall et al. (1992) has categorised GIS applications for land use planning into three major subheadings: monitoring and inventory, resource evaluation and assessment and more complex modelling and analysis (SDSS characteristics 1, 3, 5 and 6). The following section demonstrates some of the important role of GIS in the development of SDSS.

Firstly, monitoring which helps to answer a variety of questions about the distribution of existing resources and the location and extent of the recent changes. The location, extent and rate of recent or current land use changes are of considerable interest, with the comparison to the previous land use. This type of monitoring enables associations between land resources and land use changes to be established (SDSS characteristic 3). This has value in facilitating the monitoring of past changes and provides information which can help to explain how decisions producing land use change are made and tracked in relation to the resources and environment. In this context, recent satellite remote sensing plays a vital role resulting from the advantages it confers in terms of repetitive coverage, cost effectiveness, real time data acquisition and its synoptic view.

The importance of monitoring forest changes using GIS has been indicated by several researchers. For example studies applied to wild fire (Kessel, 1990; Jadhav et al., 1993; Li et al., 1997; Perry, 1998); to forest changes (Maclean et al., 1992) to disease monitoring (Vansickle, 1992); to forest road design (Martin, 1985) and to the management of timber harvesting operations (Dunningham and Thompson, 1989).

Secondly, land evaluation which gives information on the suitability of different tracts of land for selected land use identifying the forest areas capable of producing timber, or best for recreation, for rain water storage and so on (Huizing and Bronsveld, 1994; Nakamura et al., 1995). GIS has been extensively used in the field of land capability and suitability analysis applying different criteria. (Anderson, 1987; Chang et al., 1988; Juraeck, 1988; Putte, 1989; Funnpheng et al., 1994; Zuviria and Valenzuela, 1994; Rais et al., 1997).

Modelling activity based on GIS makes extensive use of the overlaying of different related attribute layers and of querying the database (SDSS characteristics 5 and 6). Examples include land allocation models using suitability analysis for fuel wood plantation (Susilawati and Weir, 1990); afforestation (Sugumaran et al., 1994a; Roy et al., 1996) and general suitability analysis for the forestry resource allocation (Zeff and Erry, 1993; Fu and Gulinck, 1994), or zonation for conservation (Ravan and Roy, 1995; Nalli et al., 1996; Ramesh et al., 1997; Verissimo et al., 1998). A GIS-based DSS has also been developed for different applications such as: to create a map of harvesting costs from maps of topography, forestry type, soil classification, management compartments, roads and streams (Herrington and Koten, 1988), predictive and habitat models (Thompson and Welsh, 1993) and harvest decision (KrcmarNozic et al., 1998).

These applications demonstrate the potential of GIS for forestry applications. Although commercially available GIS offer an appropriate technology for data inventory, routine manipulation and visualisation, they lack advanced analytical capabilities and search procedures (SDSS requirements 5, 6 and 7) (Keller and Strapp, 1993). The limitations of the present GIS may be summarised as:-

- Most of the GIS are poor in handling imprecise data. They implicitly assume that all information encoded is correct and precise (Gadish et al., 1999; Hunter, 1998; Kollis and Volitis, 1991);
- The lack of powerful spatial analytical modelling: most GIS packages spatial analytical functionality lies mainly in the ability to perform deterministic overlay and buffering operations and they are very static modelling environment (Carver, 1991; Karimi and Blais, 1996; Heywood et al., 1994).
- In addition to their query functions, GIS data base have been designed to support only cartographic display and lack an ability to interpret the meaning of results;
- Current GIS designs are not flexible enough to accommodate variations in either the context or the process of spatial decision-making;
- Currently available commercial GIS programmes lack capabilities for interactive questioning and interaction between analyst and decision maker is performed externally to the GIS (Periera and Duckstein, 1993);
- They are not good at handling qualitative data and unstructured problems (Zhu, 1995; Reynolds, 1996);
- They do not provide close links to simulation models, multi-variate and geo-statistical analysers, multimedia input and output (Reynolds, 1996).

The development of SDSS requires powerful modelling, able to handle qualitative and unstructured data, and also user friendly interfaces (See Chapter 2). In order to achieve these issues, significant research efforts have been undertaken for the lastten years by the people involved in developing spatial information systems, forexample, Reynolds et al. (1996) linked an expert system to handle qualitative data in GIS, Multi Criteria Evaluation Model was integrated with the existing GIS (Carver, 1991; Heywood et al., 1994). The major constraints that have been addressed in present GIS are the lack of advanced analytical capability and inability to handle qualitative data in order to fulfil the full characteristics of the SDSS and how some of these issues were resolved using a Model Management System is described in the next section.

3.3.2.4 Summary for DBMS

This section has showed the importance of GIS in handling spatial and non-spatial data in decision-making processes. It has also outlined overall advantages and limitations of present GIS with reference to forestry. Some of the possible solutions are outlined. It clearly revealed that Remote Sensing and GIS are powerful tools for data collection, storage and analysis of the data. However, DBMS need the integration of analytical tools and a mechanism to handle qualitative data. Several authors have suggested the integration of modelling capability through analytical models and expert systems or Knowledge Based Systems in order to overcome some of the current GIS limitations (Fedra, 1995; Zhu, 1995; Reynolds et al., 1997). The next two sections assess the use of analytical modelling and knowledge based systems and consider how they can be used in SDSS.

3.3.3. Model Management System (MMS)

The purpose of this section is to demonstrate the modelling capability within a SDSS. There are several approaches that have been proposed in order to incorporate analytical modelling with the present GIS. One approach is to develop libraries of analytical sub-routines which permits large numbers of models to be made accessible very quickly (NCGIA report, 1992). The second approach is to develop a Model Management System (MMS) which consists of small pieces of code, each of which solves a step in an algorithm as many of these steps are common to several algorithms (NCGIA report, 1992). This approach can save large amounts of code and the system developer only has to modify one piece of code to update a step in several algorithms.

A model management system would utilise the data associated with the *scenario* to be evaluated to parameterise a model or series of analytical models according to specified procedures. One approach to model management involves developing a number of analytical subroutines which can be stored, retrieved and linked together to form a specific evaluation. This allows a large number of models to be made accessible quickly. Another similar method is to develop a model base management system consisting of a number of modules, each of which solves a step in an algorithm. Both methods allow for easy modification and can facilitate the addition of new models to the system. The results of the evaluation performed by the model must be displayed to the user in a manner that makes the results easy to understand and also easy to explain to others.

In order to overcome the analytical capability problems (SDSS requirements 5, 6 & 7), several approaches have been used to couple GIS with spatial analytical models. For example, Reynolds (1996) suggested linking relational and object-oriented databases, simulation models, multi-variate, geo-statistical analysers. Multimedia input and output for environment management together with the incorporation of location-allocation models (Amstrong and Densham, 1990) and environment contamination models (Fedra, 1991; Nyerges, 1992).

Carver (1991), Keller and Strapp (1993), Pereria and Duckstein (1993), Heywood et al. (1994), Jankowski (1995) and Carsjens et al. (1996) have integrated analytical techniques such as multi-criteria evaluation in GIS to provide the user with an additional tool to the functionality of a GIS tool box. Multi-criteria evaluation is a process for combining spatial data according to their importance in making a given decision (Heywood, et al., 1994). Realising the importance of MCE, commercial software industries started including MCE as one of the modules (it is available in SPANS, IDIRISI and ARC/Info 7.01). However, MCE has four types of problem such as method uncertainty, problem definition, data un-certainity and accessibility (Heywood et al., 1994). The above outline shows some of the possible incorporation of analytical capability into a GIS in order to develop a successful SDSS.

Bennett, (1995) proposes an automated environment that supports collaborative spatial decision-making (CSDM) that would appear to be particularly well suited to ecosystem management. This is because there is often a need for consensus building and compromise and because of the analytical tools that can be brought to bear on the challenges of resource management. In complementary works such as Lilburne et al. (1997), it was clearly mentioned that to support an effective decision-making process, inter-operability must be provided within the decision support system. Inter-operability is the capability to organise and transfer information between scientific models and cross-functional components of the integrated system (van Voris et al., 1993). Host et al. (1992) suggested the need for a Hyper-text System (HS) to provide access to existing knowledge about the modelling system.

Several other studies have also attempted to overcome these problems (Leung, 1993; Fedra, 1993; Reynolds, 1996; Lilburne et al., 1997). For example, integration of Artificial Intelligence (AI) techniques such as Expert systems, (or more generally, Knowledge Based Systems) technology into GIS to tackle qualitative data problems (Reynolds, 1996). The potential of ES in GIS has been cited very often in the literature as a result of advantages over other decision support tools which do not possess the capacity for utilisation of uncertain and inexact knowledge or for learning from experience to improve decision-making skills over time (SDSS requirements 10 and 11), (Robinson et al., 1987; Robinson and Frank, 1987; Fischer et al., 1988; Burrough, 1992; Lein, 1992; Zhu and Healey, 1992; Leung, 1993; Fedra, 1993 and 1995; Lilburne et al., 1997). The next section explains in detail about KBS and how it can contribute to the generation of successful SDSS.

3.3.3.1 The role of Knowledge Based Systems (KBS) in SDSS

The last two sections have examined how up-to-date data collection through remote sensing and GIS for data storage, retrieval and manipulation and analysis can be used to support decision-making in forest planning. This section goes on to explain how AI technology can further assist in decision-making. The first section defines and explains the components of KBS. The second section demonstrates the application of

KBS to forest related studies and the value of integrating this approach with GIS and SDSS.

Often, a land manager must answer types of questions that require selecting one of several alternatives, including the decision to do nothing, or to resolve what to plant, when to plant, when to harvest, or what aspects to inventory. The decision-maker is further hampered by frequently incomplete and uncertain information associated with the technical domains involved in land management. In addition, many modern land management problems do not lend themselves to precise quantification. Many types of decision are based, instead, on judgement and experience and such problems are difficult to quantify. Many aspects of the physical and biological environment are known with only limited certainty. Furthermore, although decision-makers are knowledgeable, they are typically not experts in methods of spatial analysis and decision analysis (NCGIA, report, 1995). KBS overcomes many of these limitations particularly quantitative methods that require hard numbers and discrete decision boundaries and also provides assistance to inexperienced users (Schmoldt and Martin, 1989). In addition, many of the GIS currently available require considerable familiarity and expertise by the user, a problem that has greatly reduced acceptance of and use of GIS systems (Coulson et al., 1987). Thus for efficient decision-making, the system should support the user with a capability to handle qualitative data and support the user with expert help in how to solve the problem. KBS are very suitable for addressing such problems. The following sections describe the definition of KBS and its application with reference to forestry.

3.3.3.2. Definitions of KBS

There is considerable debate in the AI community as to usage of the term Knowledge Based System of Expert System. Feigenbaum (1984) described an ES as a computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. In another definition by Stock (1987), ES are computer programs, which use symbolic knowledge to simulate the behaviour of human experts. ES or KBS may solve problems within a narrow field of expertise and typically act as a communication medium between the expert and non-expert user (Hayes-Roth et al., 1983). The expert is a person who has acquired extensive knowledge in a certain area by way of education and/or experience. This knowledge and experience enables the expert to resolve a specific type of problem.

Expert systems are distinguished from KB systems in that the knowledge base of an expert system is not derived from generally available knowledge (e.g., textbooks, journals, etc.), but comes from experts in a problem domain (Reynolds, 1996). But most authors use Expert System in place of KBS. In this thesis KBS is used for further descriptions because the knowledge was derived from the different sources such as textbooks, journals and other personal interviews with the experts.

3.3.3.3. Components of Knowledge Based System

The KBS consists basically of a database consisting of data and knowledge and a system that controls the application of this knowledge to analyse the data. KBS normally have the following three main components: a knowledge base and method of knowledge acquisition; an inference engine; and an interface. The knowledge base contains the domain specific facts and rules and are often called "rule based systems". The rules are usually in the form of IF..... THEN. In order to create rules, knowledge should be elicited from the experts or any other sources like books, or records and then encoded into the knowledge base. This process of elicitation is called "knowledge acquisition" and transferring it effectively to a KBS is often carried out by a "Knowledge Engineer". Stock (1987) pointed out that knowledge acquisition is the bottle-neck in the construction of KBS. There are different methods available for the above task and interview is one of the common methods used for the acquisition of the knowledge.

The second component is the inference engine mechanism, which automatically carries out a search of the knowledge base for appropriate facts and rules to link them together, to form new facts and rules that can tackle the problem at hand (Kourtz, 1990). Finally, user- interfaces are devices to enable the user and expert system to communicate with each other.

3.3.3.4. Some applications of KBS in the forestry

Kourtz (1990) suggested that forestry is an ideal field in which to apply expert systems, because knowledge in forestry is distributed between process models and written materials such as textbooks, operating manuals and scientific papers. But it is also necessary to capture the unwritten forestry knowledge, from people with years of practical field experience (Kourtz, 1990). A general outline of AI techniques for forestry were explained by Coulson et al. (1987); Robinson et al. (1987); Saarenmaa (1989) and McRoberts et al. (1991). The following section examines some of the relevant applications of KBS in forestry.

As indicated earlier, the advantages of integrating GIS with an expert system have been recognised by a number of authors (Burrough, 1986; Roninson, et al., 1987; Lein, 1992; Zhu and Healey, 1992; Leung, 1993; Fischer, 1994; Fedra, 1995). These authors realised that expert systems have the great potential of adding intelligence to GIS tasks, for example in map design, generalisation, feature extraction, or spatial query. Domain knowledge represented in an expert system, together with spatial data, can provide a decision support environment in which users are guided by the integrated system towards a recommendation (Lilburne et al., 1997).

There have been a number of expert systems that are relevant to GIS problems. Stefik et al. (1982) classifies ES tasks into the following six categories: diagnostic, monitoring, prediction, planning, designing and interpretation. Examples of KBS use include, Pine beetle management (Rykiel et al., 1984), the management of aspen stands in Nicolet National Forest of Wisconsin, or suitable treatments for Red pine stands (Schmoldt and Martin, 1987). The CSIRO (Commonwealth Scientific and Industrial Research Organisation of Australia) has developed a Prolog-based KBS to predict the behaviour of fires in the Kakadu National Park (Davis et al., 1986). Other forest related studies have examined forest load location (Thieme, 1987), silvicultural practices (Rauscher and Cooney, 1986); medicinal plants identification (Sugumaran et al., 1999a); pest management (Stone et al., 1986); mapping of forest soil and forest vegetation mapping (Skidmore et al., 1996). Chandra and Goran, (1986), Demers (1986) and Kushwaha and Oesten (1995) have developed a rule-based system for site suitability for forest land use planning. They created rules by combining vegetation types, land degradation and slope characteristics for land use decisions. The above examples showed some of the successful applications developed in forestry.

KBS have proved to be very useful in forestry because of complex issues involved in the planning process. However, although KBS bring in expert knowledge to help the non-expert to take better decisions and handle inexact knowledge, they are not good at handling arithmetic and large scale data sets (Stonebracker, 1986). In addition, experts are required all through the knowledge acquisition process in the development of the integration system and, because of their widely different knowledge backgrounds, several iterations may be required to reach consensus (Lam and Pupp, 1993).

3.3.3.5. Summary of MMS

Model Management Systems deal with the incorporation of different analytical models which include multi-criteria, linear programming, location-allocation in the SDSS. In addition, in order to handle qualitative and imperfect data within the models and provide assistance to the novice user, there is need for a Knowledge Based System. However, since KBS fail to cope with large quantities of data and cannot deal efficiently with arithmetic operations and lack spatial capability, they need be integrated with other system such as GIS in order to develop efficient SDSS.

3.3.4. Display and report generator

This component provides the powerful display and capability within a SDSS to display the result output from the analysis (SDSS requirement 11). The results of the *scenario* evaluation performed by the MMS must be displayed to the user in a manner that makes the results easy to understand and also easy to explain to others (NCGIA report, 1995). A Report generator should be capable of showing the tabular data associated with both cartographic and statistical data. Armstrong and Densham (1990) comment that display facilities in SDSS should provide the following capabilities:

- high-resolution cartographic displays;
- general-purpose statistical graphics, including two and three-dimensional scatter plots and graphs;
- specialised graphics for depicting the results from analytical models and sophisticated statistical techniques;
- the full range of tabular reports normally associated with each of the above.

In order to provide all these capabilities several commercial GIS packages have recently adding a visualisation capability on their system. For example, Arcview GIS (3-D analyst), ERDAS Imagine (Virtual GIS), Arc/Info (SiteView). The next section demonstrates the importance of a visualisation tool in SDSS.

3.3.4.1. The role of visualisation in SDSS

Visualisation is a form of communication which is universal and which has the ability to form an abstraction of the real world into a graphical representation, which is comprehensible to a wide range of people (Loh et al., 1992). In another definition by McCormick et al. (1987), visualisation is explained as a computer generated graphics and audio process. Traditional tools for visual communication of resource issues have included simple graphic devices such as maps, line charts, sketches and photographs. The new tools include coloured computer maps, 3-d models, animations and interactive virtual reality environments used to explore design ideas

(Imaging Systems Laboratory report, 1995). They provide additional insights to results, which might otherwise be displayed simply as text or numbers.

Increasingly, visualisation is used to communicate the *implication* of natural and management changes in biological systems in national parks and forests (Orland, 1994). Until recently, visualisation has been an added feature, not an essential part, of the decision-making process. Too often it has been regarded as decorative in function rather than substantive, whereas it is argued here that it can form a positive and beneficial intrinsic function in management. Lately, visualisation techniques have proven invaluable in the presentation of analysis results (Church et al., 1994; Bishop, 1997). They can be crucial in supporting SDSS users to gain new insights into the structure of their problems, by generating different views of the decision situation and by exploiting their own visual skills so that they can recognise meaningful alternatives and strategies during the problem-solving process. In addition, the ability to visualise the information over space and time adds perspective to the scientists' and the decision-makers' understanding (van Voris et al., 1993; Wherrett, 1996; Bishop, 1997; Angehrn and Luthi, 1990).

Bishop (1997) showed the importance of linking modelling processes to visualisation procedures in decision-making processes, in order to achieve high levels of information presentation together with high levels of interactivity showing change over time and the results of management decisions. Recently, this technique has been widely used in natural resource management, for example, management decisions such as timber production, assessment of water catchment properties, categorisation of recreational values, construction of aesthetic values, surveys of energy usage or employment opportunities (van Voris et al., 1993; Bishop, 1997; Wharret, 1996). Natural resources management typically requires prediction of environmental changes over long time periods. The changes are also typically dependent on management decisions and constraints applied to the resource continuously throughout the management period. The complexity of the decision environment is further complicated by the distribution of management options over large areas which vary substantially in their local characteristics, their proximity to sensitive areas, the available access or their public visibility (McGaughey, 1997). The above discussion illustrates the importance of visualisation in decision-making process. The following section explains the different methods available for visualisation.

3.3.4.2. Visualisation methods

Computer visualisation methods range from simple 3-D perspective diagrams to complete virtual realities. McGaughey (1997) identified four distinct categories of visualisation techniques including geometric modelling; video imaging; geometric video imaging; and image draping.

The first method, Geometric modelling techniques build 3-D geometric models of individual features or components such as trees, buildings and roads (Smart et al., 1990; Orland, 1997). The second technique i.e. video imaging is a computer technique that "cuts-and-pastes" digital photographic images to represent changes on the landscape. This approach produces a high quality visualisation output, but it is very manually intensive, contains no direct geo-referencing to a GIS database and often suffers from the artistic/subjective nature of the creation process. Thirdly, Geometric video imaging, which is a hybrid approach combining video-imaging techniques with geometric modelling, typically undertaken within GIS. Berris (1990) illustrated the possibilities for utilising such an approach in forestry applications, yet it is rarely used on a production basis. The primary difficulty arises in accurately geo-referencing the photographic video images with the 3-D perspective framework (wire-frames) generated by the GIS system.

Finally, the image draping which is a well-established technique in GIS, involves draping an image, such as a digital ortho-photo or classified satellite imagery, onto a 3-D perspective view. Image draping results in good “texture“ and can produce visualisations suitable for depicting landscape-scale vegetation patterns. However, image draping is not effective for representing key viewpoint visualisations, typically required for evaluating harvest block layout. In most cases the forefront of the image suffers from coarse pixelisation resulting in an abstract impression. In order to determine the appropriate visualisation method factors such as the scale, level of detail and source of data should be considered.

3.3.4.3. Visualisation for forest related studies

As mentioned in the introduction, traditional tools for the visual communication of resource include simple graphic devices such as maps, line charts, sketches, photographs and also new tools includes coloured computer maps, 3-D models, animations and interactive virtual reality environments used to explore design ideas (Imaging Systems Laboratory report, 1995). Although this technique has only been recently developed, already enormous efforts have been already put into forest related studies. Some of the visualisation tools developed for forest applications are discussed next.

Hadrian et al. (1988) used a GIS to develop a partial Visual Resource Management System (VRMS) for application to a specific visual problem. They created a GIS containing topography, zoning, built forms, vegetation density and road orientation as map layers. The ALBE GIS is a very flexible, general purpose GIS for the display of a variety of data input from user supplied models. It was developed specifically to support analytical modelling and the development of decision-support applications and has the ability to integrate modelling, data management, visualisation and user interface capabilities, making it an effective tool for visualisation (van Voris et al., 1993). UVIEW also provides a variety of methods and resolutions for displaying a DTM: coarse and fine resolution profiles and grids; solid surface representations with hidden surface removal, with and without lighting (Church et al., 1994).

In the Forest Landscape Simulation Model of Kellomaki and Pukkala (1989), a computer landscape is created by placing tree symbols on the surroundings of the grid points; different species and tree sizes are represented corresponding to the theoretical tree populations. The simulation of growth with specific forest treatments is based on the theoretical tree populations created for each compartment on the basis of field data. The growth is simulated by increasing the diameter, height and age In TERRA vision prototype each tree species was assigned a rank position along the elevation/temperature gradient; these ranks ranged from 1 to 9, representing warm-site to cold-site species (van Voris et al., 1993). Arc/Info and SiteView (Kuiper et al., 1996) SmartForest (Imaging Systems Laboratory report, 1995) are some of the other examples for the integration of GIS and visualisation. The above section showed the importance of visualisation in SDSS with some application examples.

3.3.5. The User Interface

Developing simple user interfaces is another important component of SDSS development (Densham, 1991). The User Interface is what the user sees and how he/she interacts with a programme on a visual level and it is the integrating mechanism for the data, models and displays. According to Armstrong and Densham (1990), a user interface should be: -

- easy to use if it is to be effective in decision- making.
- icons can be used to represent system capabilities
- the user can select parameters, data, output, etc., easily and intuitively
- the user may be able to more easily visualize the processes represented within the model

Realising the potential importance, commercial products are including different languages and programme development environments. Examples include Common LISP (Harlequin's Interface Builder and Class works), C++, Smalltalk (VisualWorks), ArcView application development environment (Dialog Designer).

This assessment demonstrates that a successful development of SDSS requires a wide range of tools and techniques. Researchers have suggested that the key components such as database management system, GIS with analytical capability, knowledge based system or expert system, a graphical user interface (GUI), hyper-text help system (HS) and visualisation are the most suitable tools for the effective development of SDSS. It is worth explaining the advantage and limitations of each technology in order to understand and build an effective SDSS. The next section deals with different tools such as satellite remote sensing, GIS, KBS and visualisation used in developing an effective SDSS with reference to forestry.

3.4. Need for an integrated decision support system approach

The above description of the different technologies has shown the contribution that each technique or technology can make in the successful development of a SDSS for forest planning and management. Remote sensing technique helps in data collection, up-to-date information which is helps in taking timely decisions, Geographic Information Systems (GIS) provide managers with extensive capabilities for the efficient storage of forest resource data, all geographically referenced to facilitate advanced spatial analysis. Large amounts of information can be efficiently stored, manipulated, analyzed and presented, thus enhancing significantly the ability of forest managers to make informed decisions; analytical modelling facilitates the rapid development and testing of new algorithm implementation, KBS brings in expert knowledge into a SDSS to help the non-expert to take better decisions; visualisation tools assist decision-makers in gaining new insights into the structure of their problems by generating different views of the decision situation and by exploiting their own visual skills so that they can recognise meaningful alternatives and strategies during the problem-solving process; display and report generators should be capable of displaying cartographic displays, statistical graphics and plots and tabular data associated with both the cartographic and statistical displays; and finally simple interfaces assist in integrating the data, models and display the results.

It seems obvious that no single method can address all these requirements credibly and satisfactorily (Fedra, 1995) for the development of successful SDSS. The full benefits of the tools mentioned above are obtained when they are used in combination as functional components of an "integrated information system" (Bronsveld, et al., 1994) The integration of these technologies has the potential to improve greatly the efficiency as well as the power of SDSS. In order to achieve this, the above characteristics require a "common platform" which can integrate data, model, support geographic information, spatial analysis and expertise knowledge across a wide spectrum of research areas (Lam and Pupp, 1995). In order to develop an efficient single approach, a selection of tools should be put in a common toolbox. Several researchers suggested the importance of an integration of different techniques into a single system (Fedra, 1991 and 1994). Theoretical possibilities have been extensively and adequately covered in the literature (Densham, 1991; Goodchild and Densham, 1990; Moon, 1992; Enche, 1994; NCGIA, 1992; Zhu, 1994; Ray et al., 1996). Bronsveld et al. (1994) suggested that when integrating many tools, the researcher should also bear in mind the problems such as funding, training of personnel, as well as the algorithms for combining data from the different sources.

The need for an integrated system approach in environmental and resource management problems has been discussed and advocated for a considerable time (Loucks and Fedra, 1987; de Wispelaere et al., 1986; Loh et al., 1988; Fedra and Reitsma, 1990; Fedra, 1991; Heatwole, 1993; Sunday, 1999; Farnsworth, 1999). However, success stories of actual use in forest planning, in particular at an operational level, are somewhat more rare. Thus the integration of these technologies, for developing decision support system is an obvious and promising idea (Fedra, 1993 and 1994; Sunday, 1999).

Although a lot of studies have claimed they have developed Decision Support Systems for forest planning, they all only fulfil a few characteristics of successful SDSS. From the available literature, attempts to develop an integrated SDSS can be divided into three main categories, dealing with GIS or KBS alone, combinations of GIS and KBS and full integration.

Several implementations of GIS in forestry have been described as SDSS but do not satisfy the full definitions used in this SDSS characteristics (Densham, 1991). There are a number of SDSS which comes under this category. For example, the Land Accounting Management Planning system (LAMP) was developed by Sieg and McCollum (1988), which helps in timely decisions for forest fiber and other products. A forestry harvesting application using GIS was used by Riesinger and Davis (1987), Herrington and Koten (1988), Osborne and Stoogenke (1989). SYLVATICA is an integrated framework for forest landscape simulation (Host et al., 1992) and silvicultural prescriptions to optimise management of multiple resources on forests of the Eastern United States (Rauscher et al., 1995).

Most of the so-called SDSS systems just integrate GIS, data bases, ES with simple interfaces. They lack the full characteristics as defined earlier such as data base management system and model management system, report generator and user interface. Some of the SDSS use only integrate GIS, analytical modelling and ES. For example Zhu (1995) developed a SDSS for forest land use planning with Arc/Info GIS and CLIPS expert system. Although this system supports user-friendliness, analytical modelling and adaptation of user needs, it does not support powerful visualisation tools and a report generator facility. In another example, Integrated Resource Management Automation (IRMA) (Loh and Rykiel, 1992) and Integrated Forest Resource Management System (INFORMS), (Williams, 1992), the author integrated an expert system, a database management system and GIS for supporting resource managers in forest planning but do not support a powerful user interface and report generator. Some of the other examples on this category are: FORPLAN is a large-scale linear programming system used to allocate forest land to general management (Kent et al., 1991). GEODEX (Chandra and Goran, 1986) for land use planning; Diamond and Wright (1988) developed a system designed for multi-objective land use planning, which links GRASS (GIS) KES (a rule-based system) and multi-objective programming model; ASPENIX (Morse, 1987). None of these systems fulfil all the characteristics mentioned in the SDSS characteristics section.

Very recently, there have been few applications, which are trying to develop full integration approach to forestry planning. The Regional Ecosystems and Land Management Decision Support System (RELMDSS) by Church et al. 1995; Forest Management Decision Support System by Bulger and Bunt, 1991; and the Ecosystem Management Decision Support (EMDS) by Reynolds (1997) are some of the examples. The literature appraisal has revealed clearly that although a lot of DSS have been developed in the forestry sector, they have provided not all the tools necessary for forest planning or are not operational (i.e. the translation of the research into a system that are actually being used by resource managers and planners is still in an embryonic state). Significant research has been and continues to be conducted in the field of development of integrated DSS (USDA report, 1997). In this context, it is a promising area to develop an integrated operational DSS for forest planning and management using remote sensing, GIS, analytical modelling, KBS, visualisation, and local people participation for operational level planning. Development of SDSS through the integration of Remote sensing, GIS, ES, visualisation and modelling systems, each represent the best available technology in a particular application area.

3.5. Summary

Forest planning and management is complex and multi-disciplinary in nature. It requires the integration of very large volumes of disparate information from numerous sources; the coupling of this information with efficient tools for assessment and decision-making; and effective methods of communicating results and findings to a broad audience (Fedra, 1995). This in turn requires a system known as SDSS, which can support the complex decision-making process. In order to develop an effective SDSS, the components such as a data base management system, model management system, report generator and user interface are required. Several authors have suggested that these components can be provided by the integration of tools such as remote sensing, GIS, Expert Systems, analytical models, visualisation techniques and an easy user interface for the development of suitable SDSS.

The contribution of these different tools should be explicit. Remote sensing helps in monitoring and updating the data, whereas GIS brings multi source data into a common platform and allows spatial analysis. Tools such as KBS aiding the less experienced user in taking more informed decisions; visualisation provides powerful display capability and a user interface supplies easy interaction. In order to take advantage of these tools, these need to be integrated into a packaged system. Although quite a few attempts have been made to achieve this, it is still in its infancy in relation to forest planning and management. In this light, a RAnge Management Decision Support System (RAMDSS) through integrated SDSS has been developed for the Banavasi Range of Western Ghats, India. The rationale for the selection of Western Ghats and detailed description of the study area are discussed in the next chapter.

Chapter 4: The study area

This chapter examines the overall forest status of India with special reference to the Western Ghats. It starts with an explanation of the importance of Indian forests, and presents a descriptive outline including a summary of forest statistics. The second section summarises the National Forest polices for conservation. The final section deals with the present problems of the Western Ghats and the need for a new planning support system. The chapter closes with a discussion of the case study area.

4.1. The state of forests in India

India possesses a distinct identity, not only because of the individuality of its geography, history and culture but also because of the great diversity of its natural ecosystems (Indira Gandhi Conservation Monitoring Centre, 1996). The country is endowed with forest resources rich in flora and fauna and is considered as one of the world's leading "mega-diversity" nations (Rai, 1995; WRI, 1995; Gadgil et al., 1997). The forest types of the country vary from tropical rain forest in north eastern India, the Western Ghats, and Andaman and Nicobar Islands, to desert thorn forest in Gujarat and Rajasthan, rich mangroves in West Bengal, Orissa, Andhra Pradesh and the Andaman and Nicobar Islands to dry alpine forest in Western Himaliyas (Ahmed, 1997).

Forest resources in India have been classified in a number of ways. These classifications have been based on legal or functional criteria, vegetation types, or vegetation density. One of the oldest tropical forest classifications based on forest type was developed for greater India by Champion (1936) and later republished by Champion and Seth in 1968. This classification distinguishes 15 different types of forest types and was based solely on temperature and rainfall.

Until early 1980, this was the only forest classification map available for India. Since 1987, the Forest Survey of India (FSI) has taken the initiative to map and monitor the forest cover based vegetation density and types every two years (FSI, 1997), using satellite remote sensing data. So far, the forest cover assessment of the country has been done six times using satellite data procured from the National Remote Sensing Agency (NRSA) in the form of False Colour Composites (FCC). The satellite images are interpreted by skilled personnel visually and digitally. The maps show forest status for all the states in India by district. The total forest cover which includes dense forest, open forest and mangrove is estimated to be 633,397 sq.km. This constitutes 19.27% of the country's geographic area. However, the records from the forest department of India shows 23.1 % of total geographical area under forest cover (FSI, 1997). The reason for the conflicts between the records from the forest department and the satellite-based classification is the limitations of the satellite data interpretation which are summarised below (FSI, 1997):

- Minimum size in the imagery that could be mapped is 2 mm x 2 mm, which corresponds to 25 ha. on the ground, less than this size of forest patch can not be delineated;
- Since the resolution of sensor in the case of LISS-II is 36.25 metres, or by TM is 30 metres, linear features such as roadside, canal-side and rail-side plantations of size less than the resolution width can neither be recorded nor delineated;
- The young plantations where the crown has not fully developed are also not possible to record;
- Considerable details on the ground may be obscured in areas having cloud and or shadow;

- Variation in spectral reflectance during leafless period poses problems in interpretation; and
- The processing of satellite data and its generation in form of paper prints may also cause tonal variation in hue affecting interpretation.

Although there are some problems with the satellite-based interpretation and slight difference in figures, the trend of forest decrease is alarming. The detailed forest cover map (Figure 4.1) and statistics for the forest cover of different states and union territories developed using satellite data interpretation are given in Table 4.1. The next section explains in detail the reasons for and effect of deforestation in India.

4.1.1. Forest trends in India

Recently, the tremendous increase in the rate of human population, coupled with increases of livestock has caused severe degradation of the forest cover. A comparison assessment of forest cover of the country within two years (between 1995 and 1997), given in FSI, 1997 report, reveals that the total forest cover of the country has decreased from 638,879 sq.km. to 633,397 sq.km., thus showing a net loss of 5,482 sq.km. The greatest loss has occurred in the 'Tiger State' of Madhya Pradesh, which now has 3,969 sq. kms. less forest cover than it had in 1995 (Ahmed, 1997). Detailed analysis of the dynamics of forest cover across the country also reveals that from the dense forest an area of 19,456 sq. kms. has degraded to open forest, 392 sq. kms. to scrub and 3,129 sq. kms. to non-forest areas. Similarly from the open forest category, an area of 2,847 sq. kms. has degraded to scrub and 8,846 sq. kms. converted to non-forest area (FSI, 1997). The FSI report (1997) also clearly shows that out of 32 states (including 6 union territories) in India, only 10 states have fulfilled the National Forest Policy goal i.e. each state should maintain at least 33 % of its geographical area under tree cover (highlightedin Table 4.1).

The primary factors disturbing Indian forests are shifting cultivation, encroachments, grazing, illegal cutting, over population and fires. The following details on these factors are based on Ahmed's (1997) report published in the Asia-pacific forestry sector outlook study working paper series. India's forest resources suffer under the needs of a growing population. Wood is the primary fuel for the rural population and an important one for urban dwellers. Forests are also used for livestock fodder, which damages trees, and for grazing, which depletes soil nutrients and threatens plant species used in traditional medicine. Logging of timber for industrial use (for example, the manufacture of paper) and mining activities in forest areas have also destroyed forests (WRI, 1995). The encroachment of forestland for agriculture has been particularly through shifting cultivation or "slash and burn" farming and because of expanding settlement. Shifting cultivation is one of the primitive systems of raising food crops and has been in practice for thousands of years. It has become ingrained into the tradition and culture of most of the tribal groups in the country causing forest fragmentation. This practice has had severe effects in the north eastern states such as Arunachal Pradesh, Assam, Manipur Meghalaya, Mizoram, Nagaland, and Tripura. The Forest Survey of India estimated in 1987, that over 700,000 ha. of forest land suffer encroachments. It is likely that by now, the figure has increased considerably. Even though grazing is prohibited in Protected areas, in National Parks and in Sanctuaries, the forest is being degraded drastically in India due to very high livestock population. The livestock census data shows that, in 1987,the cattle population of the country was 428.4 million. An increase of 46% has been recorded between 1941 and 1987 - an annual rate of growth of 1.5 % (Ahmed, 1997).

Fire is also another major factor in the degradation of forest in India. The Ministry of Environment and Forests Report for the year 1987-1988 indicated that 1,034,000 ha. was burnt by fire. Statistics shows that 98% of the fires in the country are caused by people (Ahmed, 1997). Finally, the tremendous increase in the human population (the present population is 967 million) directly or indirectly affects forest cover. Population has increased from 360 million in 1947, resulting in a per capita reduction in forest area down to 0.08 hectare against the global average of about 1.0 hectare (Ahmed, 1997). Rapid increase in population with the associated need for fuel wood and timber for daily use has contributed to an ever-increasing amount of forest destruction. The depleted forest cover calls for the urgent possible need to plan a strategy to rehabilitate the forests and meet the genuine human needs. This has given birth to the formation of several national forest policies in India. The following section shows what has so far been achieved in the conservation and management of forests.

Figure 4.1. Forest cover map of India. (Source: FAO, 1991)

Table 4.1. Forest area cover in the different states of India.

No.	State/U.T.	Actual Forest Area sq. kms.	% of Forest Area sq. kms
1	ANDHRA PRADESH	43290	17.13
2	ARUNACHAL PRADESH	**68602**	**81.94**
3	ASSAM	23824	30.68
4	BIHAR	26524	15.28
5	Delhi	26	1.87
6	**GOA**	**1252**	**32.77**
7	GUJARAT	12578	6.28
8	HARYANA	604	1.36
9	HIMACHAL PRADESH	12521	22.45
10	JAMMU & KASHMIR	20440	9.19
11	KARNATAKA	32403	16.88
12	KERALA	10334	26.6
13	MADHYA PRADESH	135195	30.48
14	**MAHARASHTRA**	46143	14.25
15	**MANIPUR**	**17418**	**78.64**
16	**MEGHALAYA**	**15657**	**70.06**
17	**MIZORAM**	**18775**	**88.12**
18	**NAGALAND**	**14221**	**86.2**
19	ORISSA	46941	30.25
20	PUNJAB	3187	2.66
21	RAJASTHAN	13353	3.88
22	**SIKKIM**	**3129**	**44.07**
23	TAMILNADU	17064	13.66
24	**TRIPURA**	**5546**	**52.81**
25	UTTAR PRADESH	33994	11.54
26	WEST BENGAL	8349	9.32
	Union territories		
1	A & N ISLANDS	**7613**	**92.31**
2	CHANDIGARH	7	6.14
3	DADRA, NAGAR HAVELI	**204**	**41.55**
4	DAMAN AND DIU	3	0
5	LAKSHADWEEP	Nil	Nil
6	PONDICHERRY	Nil	Nil
ALL	INDIA	633397	19.27

(Highlighted figures shows the states having > 33 % forest cover)

(Source: FSI, 1997)

4.2. Forest policy and conservation in India

India is perhaps one of the few countries whose Constitution enshrines the concept of environmental protection and specifies this as the duty of the state as well as all its citizens. The first mention of forest management policies is found in Kautilya's Arthashastra, which describes this subject during the reign of Chandragupta Maurya in 300 B.C. There was a Superintendent of Forests who was assisted by some staff for protection of wild life in the forest area as a part of their duty. There were punishments for forest offences, for example unauthorised killings of elephant meant death (Chaturvedi, 1992).

The rapid exploitation of forest in the latter part of the 18th and early 19th centuries led to the development of guidelines for the conservation of forests. As a result the forest department was created in 1864 under the guidance of Dr. Brandis (Chaturvedi, 1992). Later, in 1865, the Indian Forest act came in to being as the first attempt on forest legislation by the government. A revised Indian Forest act came into existence in 1878 and it was made operational in most of the Provinces. The department of forests was expected to follow the policies adopted for the management of forests. The first National Forest Policy was proposed in 1884, with the main focus on treatment of forests prescribed on scientific consideration through Working Plans (Chaturvedi, 1992). After independence, a number of legal and policy initiatives have been taken to protect and conserve forests and wildlife, and maintain bio-diversity in general. Some of the important forest policies are discussed in the next paragraphs.

4.2.1. National Forest Policy

With the realisation that the demand for fuel-wood, fodder and non-timber forest products for local use by communities and tribal groups was rising rapidly with growing population, it was decided that the old custodial and timber-oriented system of forest management needed to be changed. The first National Forest Policy enunciated in 1884 before Independence concentrated on: (1) promoting the general well-being of the country, (2) fulfilling the needs of the people and preserving the climatic and physical conditions. However, this forest policy has a severe set-back during the two world wars, more particularly in the second World War (Tribolet, 1997). During this period, the charcoal production was increased for supply to run army trucks and most of the forests severely depleted for fuel and timber. After World War-II, forest-based industries cropped up in numbers and without restoring the forests, exploitation continued unabated (Tribolet, 1997).

This vast degradation of forest resulted in a revision of forest policy and the introduction of new policies in the years 1952 and 1988 (Ahmed, 1997). The National Forest Policy of 1952 focused on managing the forest in the interest of the people of India as a whole. The major policy initiatives includes:

- increasing the efficiency of forest administration by having adequate forest laws;
- providing adequate facilities for the management of forests and for the conduct of research in forestry and forestry products utilisation;
- controlling grazing in forests;

In practical terms, forest administration was almost exclusively intended for the purposes of increasing revenue for the State. The forests were managed with the view to producing timber for industries, railways, markets, export and for defence needs. (Desai, 1994; Saxena, 1995).

During the 1970s and 1980s, the government established a social forestry program that encouraged tree planting on private farms and community wood lots. In this approach, non-governmental organizations help local communities form partnerships with government forest departments. Together they make decisions about restricting grazing in the forests, sharing non-wood forest products such as fruits, limiting tree-cutting, etc. The role of women in management groups is crucial, because women are usually responsible for collecting and processing fuel-wood, fodder, food, and water. Non-governmental organizations help to promote participation by women and groups that are not part of the local village power structure. The new National Policy of 1988 redefined the priorities to include:

- Meeting basic needs of the rural and tribal people, especially for fuel-wood, fodder, non-timber forest products and small timber in keeping with the carrying capacity of forests;
- Raising the productivity of forests and achieving the policy goal of having 33% of the country's area under tree cover (66%) in hill areas through a massive afforestation programme in the available wastelands;
- Industry to be encouraged to develop its raw materials by interacting with the local people and communities;
- Mono-culture should not be allowed in natural forest areas with rich bio-diversity;
- Ensure people's close involvement in programmes of protection, conservation and management of forests.

In addition, there are several other policies that were formulated with different but complementary objectives. These objectives included wild life protection (The Indian Board for Wildlife 1952, and The Wildlife (Protection) Act 1972); conservation of forest with special reference to bio-diversity (The Indian Forest Act, 1927), The Forest (Conservation) Act, 1980, The National Conservation Strategy and Policy Statement for Environment and Sustainable Development, 1992, The National Action Plan for Bio-diversity Conservation 1992, and the National Bio-diversity Act, 1993). As a result of these policies, the Government of India created 77 national parks and 480 wildlife sanctuaries in order to maintain bio-diversity (Negi and Stimm, 1997). These national parks and wildlife sanctuaries cover an area about 14.03 million ha or 4.2% of the total geographical area of the country.

As a result of the priorities of the 1988 National Forest Policy, Joint Forest Management (JFM) has emerged as a new concept encouraging active involvement of local people in the protection and sustainable management of degraded lands. The principal aim of Joint Forest Management (JFM) is to ensure environmental stability and maintenance of the ecological balance through preservation and rehabilitation of forests, while providing for fuel-wood, fodder, and minor forest products and small timber needs of the rural and tribal population. The emphasis has been on the formation of Village Forest Committees (VFCs) and empowering them for participatory management of degraded forests on a benefit-sharing basis and ownership of forest lands. Ahmed (1997) comments that decentralised and "participatory" forest management is the only long-term solution to the problems of deforestation and environmental degradation in India. In addition, several international and Non–Governmental Organisations are also showing interest in the conservation and protection of Indian forest (Gadgil et al., 1983; Hobley, 1996; FAO, 1991; CMWC, 1997; FAO, 1997). In spite of these efforts, forest depletion is rampant in many regions especially in the central region which includes the Western Ghats (FAO, 1992). It is this area, the Western Ghats that forms the focus of the present research.

4.3. The Western Ghats of India

The Western Ghats of India, form one of the world's richest rain–forests and largest reserves of biological life (Myers, 1990; Ramesh and Pascal, 1991). The diversity of species and intra-specific variations in this area are unique (Rai and Procter 1986). The diversity is outlined in numerous publications (for example, Puri, 1960. Pascal, 1988; Rodgers and Panwar, 1988; Lal, 1989; IUCN, 1990; Kushalapa, 1995; Rai, 1995; Brooks, 1996). Of the 15,000 higher plants recorded in India, over 4000 species are found in the Western Ghats and, of these, 1800 species are endemic to this area (IUCN, 1990). They include 130 tree species (Myers, 1990), six mammals, and 84 amphibians (Inger and Dutta, 1987). Nearly 63 % of India's arborescent evergreen taxa are endemic to the Western Ghats (Pascal, 1988 and 1991; Ramesh and Pascal, 1991). Some of the endemic plants are (Botanical Survey of India, 1983; World Conservation Monitoring Centre (WCMC), 1988):

Actinodaphne companulata Hook F.
A. tadulingamii Gamble
Anisochilus robusta Hook. f.
Begonia floccifera Bedd.
Bentinckia coddapana Berry
Blespharispermum petlolare DC.
Bulbophyllum trimulum wt.
Centratherum sengaltherianum
Derris enthamii (Thw). Thw var.
Wightii (Baker) Thoth

Diospyros foliolosa Wall.
Diotacanthus albiflorus Benth
Elaeocarpus tuberculatus Roxb.
Garcinia gummigutta (L) Robs
Garcinia travancoria Bedd.
Hedyotis eulata (Gamb) Henry et Sub.
Isonandra lanceolata Wt.
Octatropis travancoria Bedd.
Pouzolzia wightii Benn.
Psychotria connata Wall.
Senecio carcadensis Ramas

Recently, anthropomorphic activities such as illegal cutting, encroachment for agriculture and other factors have accelerated the degradation of forest in the area. Rodgers and Panwar (1988) indicated that the Western Ghats have already lost a large part of the original forest cover and that it should rank as a region of great conservation concern. In addition, several organisations have also mentioned the extreme importance of bio-diversity in this region (FAO, 1991; World Conservation Monitoring Centre, 1988). An outline description of the Western Ghats is given below to provide a context for understanding the present research.

4.3.1. Topography and Geology

The Western Ghats constitute a series of mountain ranges that extend from the mouth of the river Tapti in Gujarat to Cape Kumarin (Kanniyakumari) in Tamil Nadu in the south, a distance of almost 1600 km. (Figure 4.2). The Geology of the Western Ghats is Pre-Cambrian, among the oldest in India. Rocks are mostly gneiss with intrusions of granite (Shyam Sunder, 1993). The Western Ghats occupy the high hills range from 700 to nearly 1900 m a.s.l. (FAO, 1993). The forests occupy the interior tracts of the coastal plain, the foot of the ghats and the mountain range which raises as a wall, with quite often vertical slopes (Shyam Sunder, 1993). The geology of this region is formed of a thick sequence of crystalline and metamorphic rocks known as the Dharwar and Aravalli system of the Archaean and composed of highly complicated metasediments (Govinda Rajan and Rao, 1978)

4.3.2. Climate

The 1600-km-long Western Ghats mountain barrier of peninsular India interacts with the southwest monsoon in a manner which bears heavily on the exceptionally varied climate pattern of the Deccan (Gunnell, 1997). The rain forests of the Western Ghats are a unique vegetation formation existing in an environment where there is marked seasonality in distribution of the rainfall. The total rainfall along the windward coasts is in the region of 3000 mm and it touches its maximum of around 7500 mm per annum in certain places at the summits of these ranges, whilst there is an abrupt fall in the rainfall on the leeward side. The forests are found in areas where the rainfall is distributed over 5 to 6 months, and as a consequence, there are 3 to 7 dry months every year. This prolonged dry period of 3-7 months renders the evergreen nature of the forests rather unique. Amount of precipitation is not as controlling a factor as its distribution over the year, as far as natural vegetation is concerned. The temperature varies from the lowest 22 C to highest 40 C.

4.3.3. Soil and hydrology

The major soil classes of the Western Ghats regions include Oxisols, Haplustalfs, Plithustults and Rhodustalfs (Govinda Rajan and Rao, 1978). They forms a sequence of red through yellow to grey soils from well-drained hilltops to poorly drained valleys is common on the back-slopes of the Western Ghats. Laterite soils are dominant and generally reddish or yellowish red in colour and often have a vesicular structure. Because of heavy rainfall, resulting pronounced leaching of bases such as calcium and are acidic in nature with pH ranging between 4.2 to 7.2. Almost all the soils were supplied with nitrogen and organic matter though most of the soils were lateritic in nature. Most of the rivers of south India originate from the Western Ghats and are major source of irrigation. The major agriculture crops in the Western Ghat regions are paddy rice, ragi and ground net.

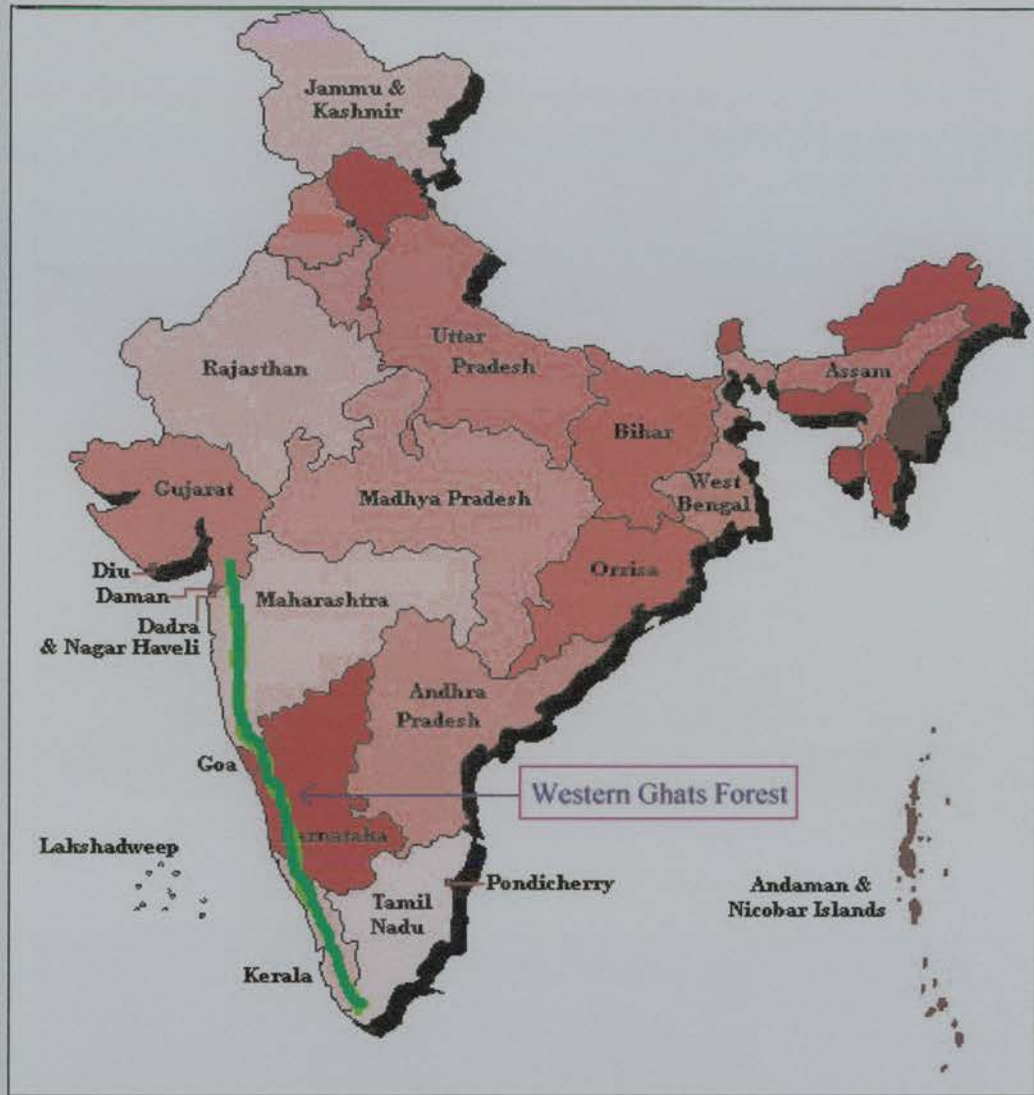


Figure 4.2. The extent of the Western Ghats (green line)

4.3.4. Vegetation

The vegetational diversity and floristic richness of the Western Ghats is remarkable and contains some of the best representatives of non-equatorial tropical evergreen forest in the world (Pascal, 1988; Pascal, 1991). These hill ranges accommodate many different vegetational formations such as evergreen forests, moist and dry-deciduous forests, *montane* forests, *sholas,* scrubs and savannas. The forests have considerable diversity in vegetation types both with respect to their altitudinal locations and also to edaphic controls. Figure 4.3 shows the example of evergreen forest in the Western Ghats.

Currently, the forest area covers roughly 38,610 sq. kms. which includes rain forest and monsoon forest (FSI, 1995).

Figure 4.3. Evergreen forest of the Western Ghats

The forest in the Western Ghats is of four main types and twelve sub-types as classified by Champion and Seth (Tiwari, 1993). The main types are

1. Tropical wet evergreen forest
2. Tropical semi-evergreen forest
2. Tropical moist deciduous forest and
3. Tropical dry deciduous forest.

The categories semi and wet evergreen forest, the most luxuriant and diverse vegetation on earth, possess several gigantic trees e.g. *Artocarpus incisa, Hopea wightiana, Knema attenuata, Pithecellobium bigeminum, Garcinia cambogia, and Terminalia bellerica.* These trees tower over the general level of the forest and the stature of the trees is surprisingly varied between 15 and 45 meters. In this forest type there are numerous epiphytes especially ariods, ferns, mosses and orchids with a near absence of ground vegetation.

The deciduous forest occupies about 50 % of the Western Ghats. It is the home of rosewood (*Dalbergia latifolia*), Indian laurel (*Terminalia tomentosa*), Kino (*Pterocarpus marsupium*) and many other hard wood species (Shyam Sunder, 1993). The rich florostic diversity of this area is now under tremendous pressure because of anthropogenic activities. The following section details the present problems of this area.

4.3.5. Present problems of the Western Ghats

Over the past five decades, activities such as illicit cutting, land encroachment for agricultural expansion and settlements, reservoir flooding, logging and over-exploitation have drastically disturbed and reduced the forest at an alarming rate (Indira Gandhi Conservation Monitoring Centre, 1996). The original primary forest of 50,000 sq. kms was estimated to have been reduced to 8000 sq. kms by 1990 (Myers, 1990). As a result the Western Ghats region is considered as one of the endangered 'hot spots' of the earth by IUCN, this designation being based on the number of original plant species, the extent of the remaining area today and likely remnants which may survive in the next century (Myers 1988 and 1990). The economic and biological importance of these forests and the threat to their very existence, due to unorganised exploitation of forest resources, has emphasised the need for a better knowledge of the dynamics of this ecosystem leading to a more sustainable management policy. The next paragraph explains what has been achieved so far in the conservation of forest in this area.

Forest management history started in the Western Ghats with the banning of kumri cultivation (viz., temporary cultivation in cycles after felling and burning of the forests) in the 1860's (Someshwar, 1991). In the beginning of this century, sustainable forest management through Working Circles (for protection, felling and plantation) was introduced in order to control forest degradation. Later, the Working Plan system was introduced throughout the main forest departments. This major role of these plans is related to timber production and is prepared for periods of 10 years. At the end of each 10 year period, the results are analysed, and reviewed and revised working plans are prepared. Some of the important working plans are: Ravann's working plan for

Govardanagiri state forest (Ravann, 1924) which concentrated on timber and fuel for the villagers in this area; the Kadambi working plan for Shimoga and Sagar division (Kadambi, 1945) which concentrated on the requirements of the people including small timber poles, posts for house building etc.; and the Kanara division plan (1960), which explained the requirements of the people for firewood, timber, agricultural implements. These Working plans are mainly concentrated on timber and fuel wood for the local people.

After 1970, several international organisations such as FAO, World Bank, ODA (Now Department For International Development, DFID) helped to develop the forest management in this area. In the 1970s and 1980s several reforestation programmes were initiated and implemented through social forestry projects with international aid. In 1994, the Overseas Development Authority, UK, funded a project called the "Western Ghats Forestry and Environmental Project" to attempt to rehabilitate the forests in the Western Ghats, with the objective of restoring long term sustainable management. In addition, in 1997, several National Forest policies were revised and a National Forest Action Plan was started in order to use the forest. In spite of these efforts, forest degradation is still proceeding at a very rapid rate in the Western Ghats. This situation calls for a new planning approach in this area.

4.3.6. Why is a new planning system is needed?

The current system of planning and management (Working plans) has a number of weaknesses. The KFD and Project Process Development Programme report (PPST report 47 and 49, 1997) clearly documents the limitations of the present planning system which are summarised below:

- The working plan is a document produced to addressed the strategy set out under previous forest polices in India (NFP of 1984 and 1952), notably the scientific management of Reserve Forest to maximise revenues to the state, mainly from timber;

- With a new forest policy aimed chiefly at environmental conservation and meeting local needs from the forest, the working plan process has become less relevant to the forest managers;
- Currently, the green felling ban does not allow harvesting of green trees, but the major purpose of the working plan is to provide a program of extraction of such timber;
- The working plan is prepared centrally, incorporating a limited consultation process with local users and other stakeholders, and no planning for local needs;
- Many Working plans are out of date by the time they are implemented, and do not allow for unplanned changes in forest structure which may have occurred since the inception of the current working plan;
- The available information in this area is out-of-date, and at different scales and formats, compiled for specific purposes and often from a single rather than multi-sector perspective. This has led to difficulties in integrating and analysing data by current methods.

The present planning system is based on a top–down approach. The District Forest Officer (DFO) (See the hierarchy in the Figure 4.4) writes a working plan after collecting the data through field visits. Then it is implemented through a Range Forest Officer (RFO) (Figure 4.4). This top–down approach does not allow the participation of the local people in the planning process, and collection of data is through a traditional ground survey, which is time consuming (Lakshmi et al., 1998b). Furley and Harrison (1995), a Series of Process Development Programme Reports, (PPST47 & 49, 1997), and Singh (1997), have clearly indicated the limitations of the present planning system. These limitations, along with the need to incorporate the priorities of the latest NFP identified and to develop a new flexible, participatory (example JFM) multi-purpose forest planning methodology. This methodology should use appropriate technology to allow the planner to collect data more efficiently, increase the capability of storing and retrieving the collected data, and also include local people in the planning process. Lately, several reports suggest that a modern information-based system using remote

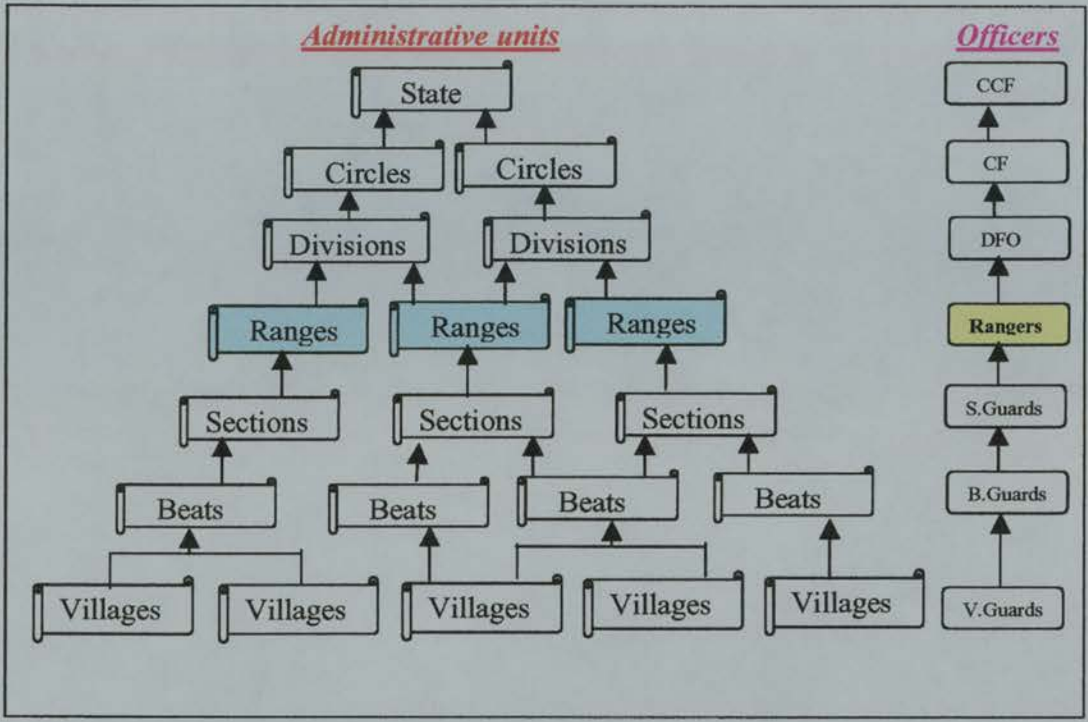


Figure 4.4. Administrative hierarchy in Karnataka Forest Department

Modern tools like remote sensing, GIS (Geographical Information Systems) and MIS (Management Information Systems) can be used to hasten the process of building up lost ground in forest management. Forest management has to be technically sound, environmentally compatible, commercially viable and socially acceptable and its ultimate aim and approach has to be humane and people-oriented (FAO, 1997). Realising the importance of these tools several case studies were undertaken which are explained in the next paragraphs.

Many scientific publications have recommended using modern methods of monitoring and management of the Western Ghats (Chandran, 1997; Daniels, 1997; Pramod, 1997; Ramesh et al., 1997; Carpentier et al., 1998; Lakshmi et al., 1998a; Menon and Bawa, 1997; Nagendra and Gadgil, 1998; Pelissier, 1998; Pelissier et al., 1998; Prasad, 1998; Prasad et al., 1998). These studies have only concentrated on the data collection through remote sensing, and simple spatial analysis using GIS. Furthermore, no DSS

1997; Nagendra and Gadgil, 1998; Pelissier, 1998; Pelissier et al., 1998; Prasad, 1998; Prasad et al., 1998). These studies have only concentrated on the data collection through remote sensing, and simple spatial analysis using GIS. Furthermore, no DSS related studies were reported in this area. The details of the published studies in this area are discussed below.

As mentioned earlier, the available publication in this area uses only mapping of forest area, or some simple GIS based studies. For instance, Hegde et al. (1994) used remote sensing successfully for analysing the changing land use and land-cover pattern in the Kali river basin in Western Ghats. In another case study, NRSA (1995) prepared a detailed forest land cover map (1:25,000 scale) using aerial photographs and satellite images (IRS-1B data) for the North Cannara circle as a part of current DFID sponsored project. The aim of this project is to develop detailed forestry inventory maps for strategic planning at divisional level. The project is still in progress and recently developed a Computerised Range Management Information System (CoRMIS) for data collection at the Range level (KFD report, 1996).

In another study, broad-scale mapping (at a 1: 1,000,000 scale) of the Western Ghats into different landscape types, using IRS 1B imagery with a Normalized Difference Vegetation Index (NDVI) was attempted by Nagendra and Gadgil (1998). Detailed maps of forest type for the North and South Cannara circle were prepared by Pascal et al., (1995) using visual interpretation of Landsat TM data and IRS images. Lele et al. (1998) used 1:35,000 scale aerial photographs from 1973 to generate a detailed land-cover map, and overlaid the legal forest survey maps and village boundaries to associate forest condition with the village-level socio-economic data. The differences between their land-cover map and an official forest cover map for that region are significant. Some of the other case studies include Kimothi and Jadhav (1986); FSI (1995, and 1997) using satellite data for forest type and forest density mapping in the study area. These studies demonstrate the different approaches and outcomes of remote sensing in the study area but none of these provide any insight into the decision-making process or forest planning. Recently, however, a few case studies attempted to achieve the above goal using GIS.

A GIS based study for the study area has been carried out recently by few researchers. Some of the case studies are given below. Ramesh et al. (1997) and Menon and Bawa (1998) have produced a vegetation-based approach to bio-diversity gap analysis using GIS in the Agastyamalai region. They have used a detailed map of existing floristic types and used it to generate layers corresponding to floristic species richness, zones of floristic endemism, floristically unique areas, and habitat distribution of representative endemic faunal species. In another interesting study, Lakshmi et al. (1998a and 1998b) used RS-GIS for the development of a Forest Resources Information System at divisional level to micro-level planning in Joint Forest Management areas for the inputs for forest working plans. Prasad (1998) and Prasad et al. (1998) demonstrated the importance of GIS tools to analyse habitat loss, and transformation over a period of 30 years beginning from the late 1950s for the Western Ghats. These few studies in the study area are a step forward towards supporting a decision-making process in the forest planning and management, but no studies are available for the development of decision support system for the forest planners in order to support their day-today planning process in the study area or other areas of India.

The above discussion shows that in order to overcome the current Working Plan system limitations that mainly (1) emphasis extraction of timber; (2) do not allow the participation of the local people in the planning process, and (3) have the problem of data collection through traditional ground survey, which is time consuming, it is argued that, there is a need for integrated decision support system for improved planning and management. Although, many case studies have been undertaken in the study area using remote sensing and GIS, no single study has be able to overcome these problems of the present planning system. Keeping these views in mind, in the present study, an attempt is made to develop a RAnge Management Decision Support system (RAMDSS) in the Western Ghats, to assist forest planners, in order to overcome the identified weaknesses of the current planning system and to develop better planning and management procedures.

In order to demonstrate the integrated approach of DSS, the Banavasi range of Sirsi division in the Western Ghats was selected. The reason for the selection of the Range is that it is one of the smallest working unit in the Karnataka Forest Department (see Figure 4.4), it has available an extensive data base collected in the DFID project, and documented history of the area. In addition, the Banavasi Range was identified by the forest department and other organisations as a potential area for conservation, because of the fast forest degradation, population pressure and other problem such as pressure of livestock on forest etc. (KFD report, 1997). The importance of conserving this area was also reported by several authors (Lele et al., 1998; FRLHT, report, 1997; Pelissier et al., 1997). The Banavasi range occupies the east of the Sirsi division, and covers an area of 66649 acres between latitude 74^0 50' 75^0 05' and longitude 13^0 55' - 14^0 45' (Figure 4.5). The area has 76 villages and a population of 39908.

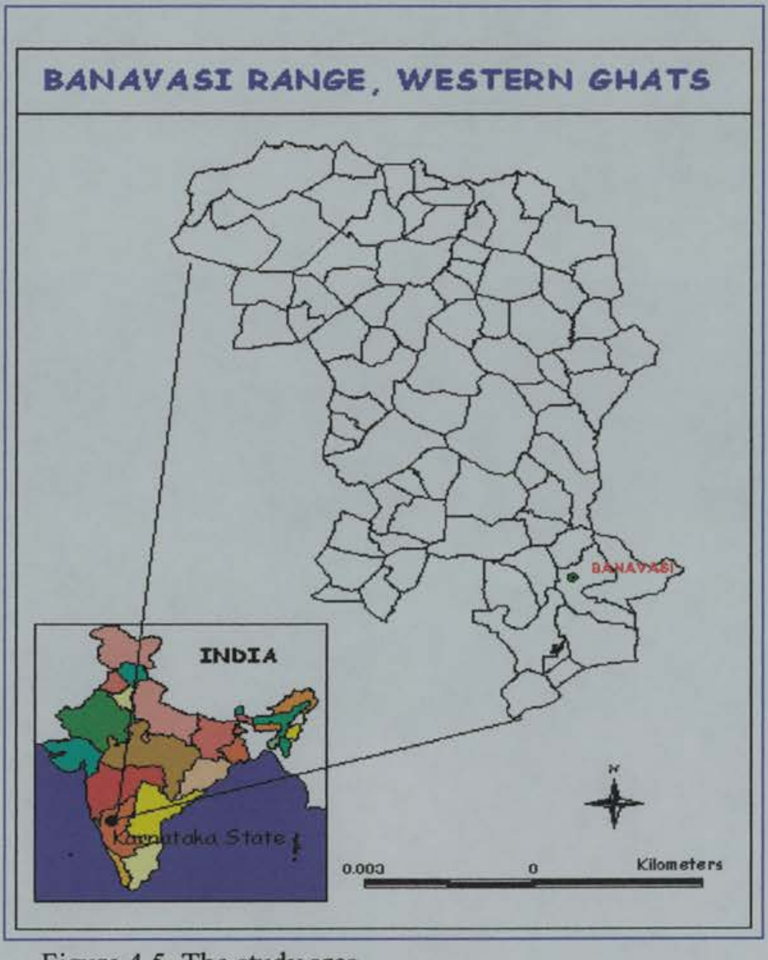


Figure 4.5. The study area

The severity of problems of forest degradation, coupled with population pressure of people and cattle along with poor data quality and availability are some of the reasons for the selection of the Range Banavasi in the Western Ghats.

4.4. Summary

This chapter discussed the problems of Indian forests and emphasised the urgent need for conservation of forest resources. The primary factors disturbing Indian forests are shifting cultivation, encroachments, grazing, illegal cutting, over-population and fires mainly in the north-eastern states and the Western Ghats. The chapter also discussed the different forest polices developed and implemented in order to control the deforestation. In order to study the issues in detail, one of the fast forest degrading area, the Western Ghats of India was selected and analysed for its importance, problems and polices. One of the major problems in these areas includes the traditional forest planning and management practice called Working plans. Finally, to overcome these problems in the present planning system, a new approach is suggested through the development of a Decision Support System.

Chapter 5: Development of RAMDSS

The development of a Range Management Decision Support System (RAMDSS) is explained in four chapters (chapter 5, 6, 7 and 8). This chapter describes the stages involved in the development of the prototype. Section 5.1 covers a short overview of different "life cycles" in development of relevant software and discusses the selection of a suitable model for RAMDSS. This is followed by a section which describes the process of defining the user requirement for the prototype RAMDSS. Chapter 6 discusses the conceptual design and implementation of the software, and testing the prototype. Collection of relevant data and processing will be discussed in chapter 7 Finally, Chapter 8 demonstrates application examples with a case study taken from the study area.

5.1. Development stages in RAMDSS

One of the first steps in the development of any software is the introduction of the concept of a software life cycle (Sasse and Fulton, 1998). It is simply a model of the stages or steps, by which a software development project is initiated, developed and completed. In addition, it also provides guidance on the order in which a software development project should carry out its major tasks (Paul, 1998). A bewildering variety of software life cycles are in use today, for example *waterfall, rapid application prototype,* and *spiral model.* The following section explains three different software life cycles and their advantages and limitations.

The most popular, and certainly the best known, is the *waterfall model*. The analogy of using a description of a stepped waterfall helps to explain how such a structure can work. Water flows from one step of the waterfall to another. The effects of gravity and the pressure of the water current prevent water returning to previous (higher) steps in the waterfall. Steps, therefore, must be completed by the flow of water in a predictable, and linear, manner (Figure 5.1). Although this model is the most popular, it has the following problems (a) the fact that real projects rarely flow in a sequential process; (b) it is difficult to define all requirements at the beginning of a project; (c) this model has problems adapting to change; and (d) a working version of the system is not seen until late in the project's life (Sasse and Fulton, 1998).

In contrast, the *Rapid Application Prototype* (RAP) methodology executes all these steps in parallel to waterfall model (Figure 5.1). RAP refers to a development life cycle designed to give much faster development and higher-quality results than those achieved with the traditional life cycle. The initial working application becomes an aid to analysis and design, by giving users a concrete context for feedback, rather than abstract diagrams. Users participate in testing, and development becomes an iterative process of refining successive versions of the application (Figure 5.1). The problems with the RAP method are that (a) the customer is likely to want the earliest working version which may not be well engineered for quality and long term maintainability and (b) a less than ideal implementation may have been used to produce the prototype (i.e. an appropriate programming language was available, or a less than ideal operating system was available).

The third method, the *spiral model* uses the best of the waterfall model and the rapid prototype model. The spiral model development process is divided into four quadrants (Planning, Risk Analysis, Engineering, and Customer evaluation) (Figure 5.2), (Paul, 1998). Starting at the planning quadrant you move in a clockwise direction through the quadrants spiralling outwards until you have completed a final product.

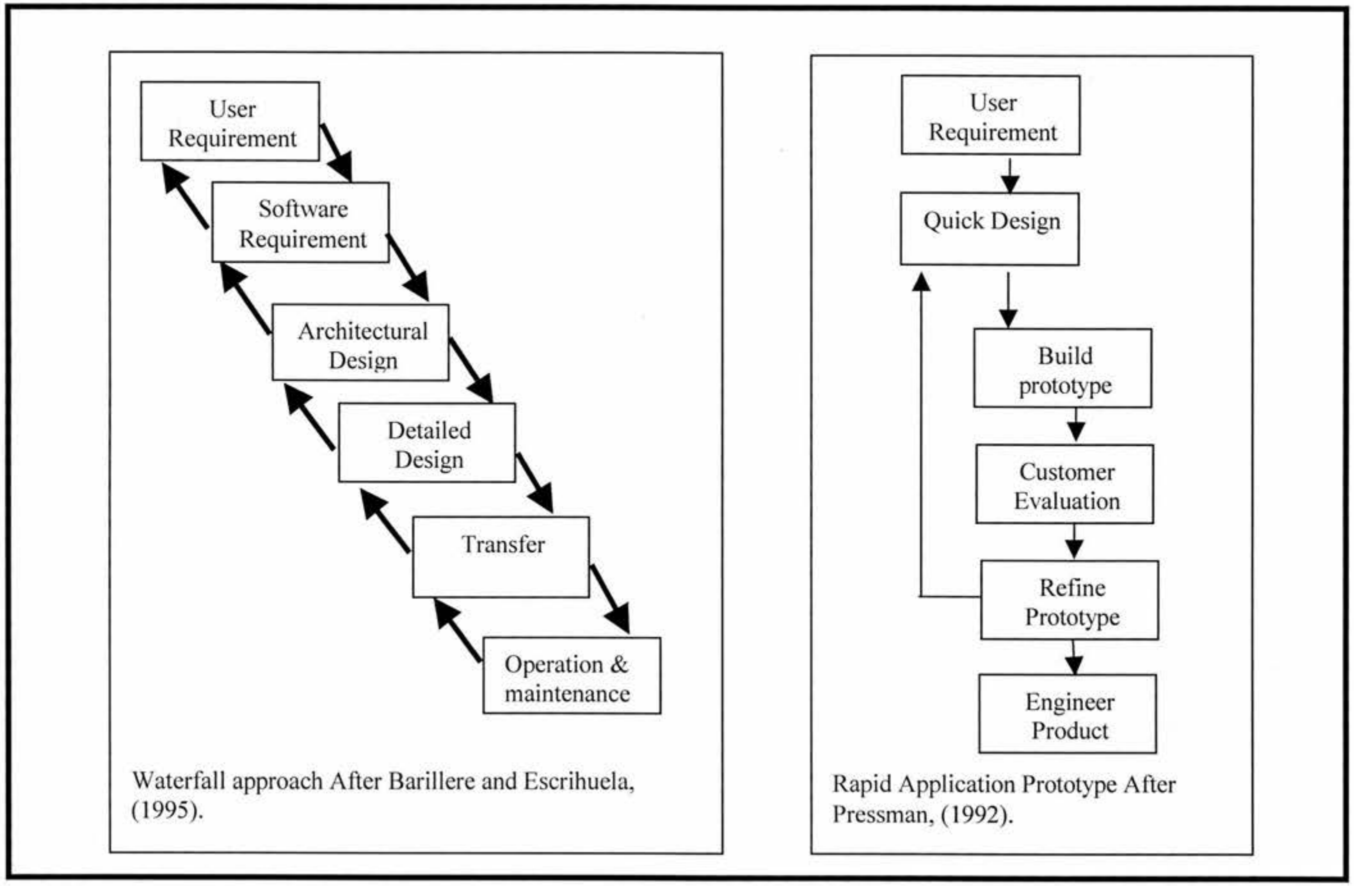


Figure 5.1 Comparison of Waterfall and Rapid Application prototype approaches

At each interaction cycle a progressively more complete versions of the prototype is built based on the customer evaluation. This approach follows the same logic of the RAP model but it mixes the water type model.

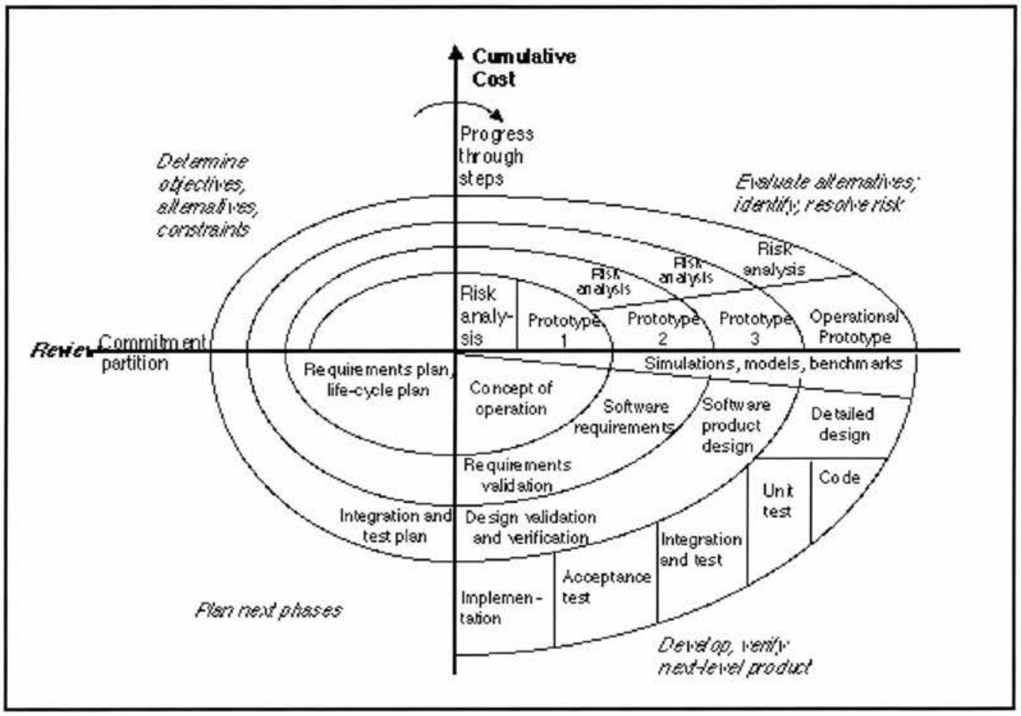


Figure 5.2 Spiral model (After Paul, 1998)

This is the most realistic approach to software development. Nevertheless there are problems with the spiral method such as: (a) it may be difficult to convince the customer that an interactive approach is controllable, and (b) that the engineering staff will always want to improve the design/product.

After studying the different approaches, it was decided that a mixed methodology is appropriate for the present study because the parameters require a highly structured, high-speed methodology involving a high level of user interaction. These demands could not be met in any one system's development methodology and therefore, components of several methodologies were mixed. This activity is advocated by Pressman (1992), since it should enable the developer to get the best of all worlds. Figure 5.3, describes the attempted mixture of RAP, Spiral and the traditional

Waterfall methodologies. The advantage of the waterfall method is that it helps clearly to schedule milestones for management, and the spiral (or iterative) method is the best way to reduce risk as the software application for the development of the prototype. Because of these reasons the mixed methodology was adopted. Figure 5.3 illustrates the life-cycle stages employed in this project utilising a mixed model. The following section discusses in detail each step involved in the development of the prototype RAMDSS.

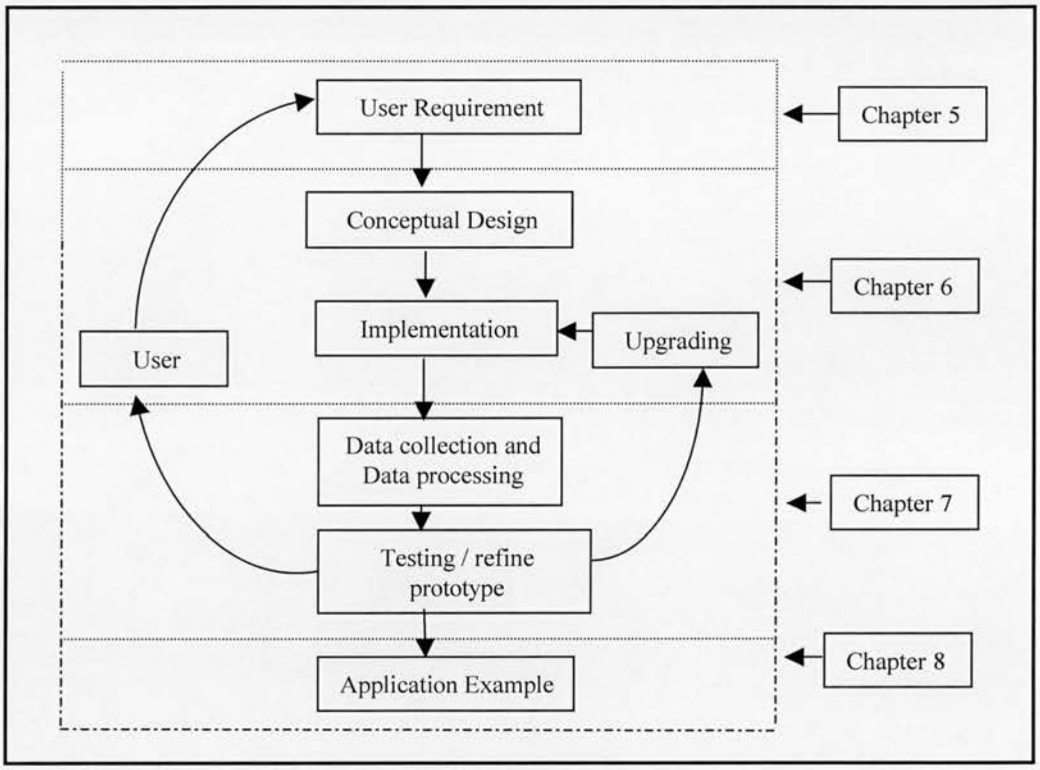


Figure 5.3 Stages in the RAMDSS life cycle

The first stage in the life cycle is to understand the user requirements from the potential users, in this example from forest officials or planners. After collecting the user requirements data, the conceptual design is constructed in order to plan the process involved in the development of the prototype (Figure 5.3). The conceptual design is followed by the implementation of the software using appropriate tools. The conceptual design and implementation will be covered in the next chapter

(Chapter 6). The data collection and data processing (Chapter 7) and application example will be demonstrated in chapter 8 using RAMDSS. If the user wants to modify the requirements or changes in any module, this can be effected through upgrading the prototype (Figure 5.3). The detail of the user requirement stage is explained in the next section.

5.2. User Requirements Specifications

Building a requirement specification is a crucial activity in any software development process. Requirement analysis typically involves two stages: identification of potential users or stakeholders, and elicitation from the users of the features they would like to see included in the final software (Young, 1998). A number of strategies are utilised in order to gather information about the client and the system to be built. It is important not to set up the requirement specification or build/evaluate the prototype in a mechanical way, but instead to approach this creatively. This section concentrates on the extent to which user requirements are accurately defined within RAMDSS.

5.2.1. Identification of potential users

Due to the small number of users, the interviews were carried out on a detailed, 'one-to-one' basis with different managers. These included Forest guards, Range Forest Officers (RFO), District Forest Officers (DFO), and Chief Conservator of Forest (CCF). The use of highly structured techniques such as questionnaires seemed inappropriate because of the user background or knowledge about the computer. It was decided that open-ended interviews would be used as a simple approach to user requirements capture, (Preece et al., 1994). The main questions were planned out in advance to maintain some structure and direction to the process. During the interviews the following major points were raised and discussed with the forest personnel. Some of the examples are given below.

- Who is the potential user of the system?;
- User level requirements;
- Where to set up the system (Range level, Division level, Circle level or State level)?;
- Who maintains the system?
- Why the development of DSS?
- What is required to develop a DSS?
- What the system should provide to the user?
- How it can be linked to all forestry sectors?
- What platform should be used (Unix, or PC or Vax/VMS)?

After several days of discussions with forestry professionals, the following preliminary issues emerged. The preliminary analysis was more about the technical and general issues rather than a specific user requirement for the prototype. The conclusion of the preliminary discussion is follows: the Range was selected for setting up the system because it is one of the smallest working units within the Karnataka Forest Department (See hierarchy detail in chapter 4, Figure 4.4). The Forest Ranger is responsible for managing the whole Range and will be the potential user and he /she will be using it for day to day operational planning. Once the system is successfully implemented at the Range level, then it can be extended to other Ranges, as well as to division level, finally to Circle level (See hierarchy detail in chapter 4, Figure 4.4) for strategic planning.

In order to undertake a case study, the Banavasi Range of the Sirsi division was selected. The reason for the selection of the Banavasi Range was discussed in chapter 4. The name RAnge Management Decision Support System (RAMDSS) was given because it deals with the Range level in the study area. Furthermore, the personal interviews also showed that there are two main groups of user: planners with limited experience in forest planning, and planners with a lot of experience. In order to support the novice user, the system should provide some expert opinion.

After identifying the user and study area, the interview focussed more on the study area and the forest officials involved in that area. Several issues were discussed with the users about the requirements. Finally based on the discussions, the requirements were grouped into six major categories: forest inventory, production forestry, protection forestry, presentation of information, user interaction with the system and general requirements. Each category is discussed in detail and given below.

5.2.2. Forest inventory and analysis

The Forest Inventory and Analysis (FIA) objective is to determine periodically the extent, condition, and volume of timber, and to monitor the growth or depletion of the forest. Up-to-date resource information is essential to frame forest policies and programmes. Range officers are responsible for conducting these inventories and publishing summary reports for individual Beats, sections and Ranges. The requirements of a DSS to support this task include:

1. *System should be able to facilitate the updating of forest inventory records; socio-economic data and other administrative records using existing formats.*

The main purpose of this requirement is to develop an efficient method of collecting, storing and updating of the forest inventory, socio-economic, and administrative data in order to change the traditional system of the paper and pen method. The system should replicate the present method of data collection with an automated one. For example it should provide simple user input forms with the same format as the traditional method.

2. *System should provide the facility to display and query the forest inventory data.*

The main aim is to display the forest inventory data and also to allow the inexperienced and newly posted Range Forest Officer (RFO) to query or to explore the forest inventory and other existing data. For example, to view the forest land use / land cover statistics or maps, locate the fire watching towers, or check-posts in the study area etc. by a simple user-friendly query. The query should display the result in different formats such as graphical and tabular formats.

5.2.3. Production forestry

Production forest is clearly designated as the area of forest to be managed for 'commercial value'. For example, income generated through harvesting of plantations and collection of dead and fallen timbers. In this thesis, Production forest is based on the requirement for a source of income from the forest area. Although the forest sector in KFD is not managed primarily to balance the income and expenditure from the forest, the major daily planning process for the forest planner includes finding out how much dead and fallen timber is available in the study area and where to collect these timbers or how much non-timber forest produces is available etc. Based on this assumption, the forestry planning requirement was classified into production forestry (mainly income from the forest) and protection forestry (expenditure to maintain the forest). The production forestry objective is to find suitable areas for the generation of income from the study area. The requirement includes:

3. *The system should provide methods of finding the suitable areas for generating money.*

Although green felling is banned in India, the collection of non-timber produce is allowed. The major sources of income from this sector are through tourism, collection of dead and fallen tree timber, non-forest timber forest products, and harvesting plantations. In order to find these areas for raising revenues, the system should provide information to satisfy any income-generating queries. The collection of dead and fallen timber is usually done once every five years or whenever the Government requires urgent money for the development projects. The collection of non-timber produce such as Beedi leaves, honey, cane, medicinal plants etc is permitted to generate only limited money from the study area.

5.2.4. Protection forestry

Forest protection is concerned with identifying and assessing factors that impact on the forest in order to take suitable conservation measures. This requirement mainly concentrates on the extent of the area affected by fire, soil erosion, grazing etc and how much money needs to be spent in order to protect, conserve, or rehabilitate the area.

4. The system should provide methods of finding suitable areas for the protection.

The important areas to be protected include, fire, plantations, encroachments, quarrying, medicinal plants, and bio-diversity. As an example, suppose a forest planner wants to find out suitable areas for fire protection: then the system should be able to identify the suitable areas, based on natural features such as forest types, slope, causal factors, and fire history.

5.2.5. Presentation of the information

The most flexible way to display data retrieved from a RAMDSS is to define a result output. The results of the analysis can be displayed graphically in the form of charts, graphs, maps, tables or reports. One of the important jobs for the RFO is to generate a village map, plantation survey map, forest survey map, etc to the beat and section guards in order to monitor the encroachment of land by the adjacent farmers. The requirement includes:

5. The system should provide an easy way of making maps.

As mentioned above, the RFO is responsible for providing maps to village guards, section guards and beat guards in order to collect the detailed information about their forest resources. In order to achieve this, the system should provide the required map by an easy method. In addition, the user does not require much cartographic qualification to make the maps.

6. The system must also support tabular output of the result.

In addition to easy map-making, the system should also have the capability of generating automatic tabular statistics. The RFO's job also includes the preparation of annual reports regarding the money spent on different development projects and income from the Range. The system should also support this facility.

5.2.6. User interaction with the system

The system should be easy to use, flexible, interactive with a simple user interface. The user interface is the integrating mechanism for the data, models and displays. Most planners are not experienced users, so the system must allow non-technical users to use the system without a long learning curve. The user interface enables the decision-makers to manipulate the database, provide the alternatives, and view the result in an interactive session. The major requirements for easy interaction are:

7. The system must be usable by the planners with a limited technical background in decision-making.

The system should help the inexperienced planners, by providing some expert opinion or advice to solve specified problems during the decision-making process.

8. The system should provide adequate description about each problem or model.

This requirement demands that a detailed description of each model or option provided by the system should be given if required by the user. This can be made available either through a hyper-text help system or tutorials.

9. The system should provide easy methods for user interaction.

The system should have an easy user interface in order to understand the different functions available within it. The planner does not want to spend time in learning the new system but rather to concentrate on the important issues such as conservation or protection of area. This can be done with simple Graphical User Interface (GUI) with icons or buttons.

5.2.6. General requirements

This category does not fall into the groups mentioned above. It is mainly related to the technical issues such as what are the systems requirements, hardware and software?

10. The system should be to easy to maintain.

The system should be PC-based in order to minimise the maintenance requirement. It is appropriate to develop the system with a simple window interface and be PC-based.

11. The new system should not be expensive.

This requirement encourages the use of existing software and hardware. Buying new software and hardware should not be necessary unless user requirements cannot be met.

After a successfully addressing the user requirements, the prototype system was constructed. The design of the RAMDSS system includes a wide variety of analytical functions in order to support the users and help them to obtain better solutions. It also provides a framework that guides the user through the planning and decision-making process.

5.3. Summary

This chapter assessed the selection of a suitable software planning cycle for the development of a prototype. A mixed methodology was chosen after reviewing different software planning cycles such as waterfall, Rapid Application Prototype, and spiral models because the prototype require a highly structured, high-speed methodology involving a high level of user interaction. After the selection of the appropriate life cycle, the first stage (i.e. the user requirements) was derived from forest department personnels and the requirements were grouped into categories which would define the behaviour of the system. Five major categories were identified including forest inventory, production forest, protection forest, presentation of the information, and user interaction. The next chapter discusses how the conceptual design was achieved based on these user requirements and how it was implemented with the available development tools.

Chapter 6: Design and Implementation of RAMDSS

Chapter 5 discussed the different stages in the software development and user requirements for the development of the prototype. This chapter presents in the first section the conceptual design used in the development of prototype. The second section demonstrates how the conceptual design is implemented with different development tools. The final section develops the system architecture and a user-friendly interface within RAMDSS. The design of the prototype RAMDSS involves the articulation of the entire process of data flow, which includes developing a conceptual design, and implementing the conceptual design.

6.1. RAMDSS prototype design

Prototype methodology is a method of developing systems for users where the systems methods of analysis, design, and development are conducted in parallel, rather than sequentially as in traditional methods of development (See Chapter 5). Prototypes, when constructed, are used by the users and they supply the feedback. The prototype may require enhancements, improvements or modifications, which have to be ascertained in detail from the users before the prototype is modified to meet those requirements. The prototype is used again and if any additional needs arise, they are incorporated into the prototype and the process is reiterated. In general, prototyping is an iterative process and continues until such time as the prototype fully meets the requirements of the system specification and the users are happy with the result. This principle has been applied to RAMDSS. The first step in the development of a prototype design is the conceptual design. The details of the development of the conceptual design for RAMDSS are discussed below.

6.2. Conceptual Design

Design is an activity that recognises the goals or purposes of products or systems. It is also a decision-making process that transforms abstract user demands into a specific product. Design refers to the conceptual phase of development between the user requirement and the implementation phase. Conceptual design involves explicitly defining the ideas or concepts underlying the user interface of a product, in other words, the conceptual model represents the users view of the interrelationships between data sets stored in the database (Healey, 1991). A correct conceptual model is vital because, if it is built incorrectly, the likely outcome will be an inefficient database structure with unnecessary redundancy in data storage and a poor match to user's requirements (Healey, 1991). A conceptual design contains product functionality (what it will do) and architectures (what will it do and how is organised). This applies to the current RAMDSS system.

The conceptual design framework synthesizes many user-centred design principles and practices and consists of the following: definition of a central concept, description of the users and their requirements, definition and prioritisation of measurable objectives and constraints, design of the user's object model, design of the user's task model, synthesis of a user interface model, and evaluation of results against the objectives. Conceptual design starts with an understanding of what users really need, and is followed by an easily communicated set of models that capture this understanding. In order to understand the design of component-based solutions, there are two distinct perspectives involved: Logical Design and Physical Design. Logical Design describe all functional features of the system independent of any computer platform (Logical Specifications), whereas Physical Design transforms logical design into technology-specific details.

Several techniques have been developed to describe and design conceptual models. In general, there are three major techniques used in conceptual models: - *Data Flow Diagrams* (DFD), (Ricardo, 1990); *Entity Relationship Modelling*, (Worboys, 1995) and *Normalisation*, (Worboys, 1995). Although there are different techniques available, in the present study, DFD was used to construct the conceptual model because it helps the planner to develop architectural description, showing data interchange between the sub-systems. Also it is easy to show processing at different level of abstraction from fairly abstract to fairly precise.

Data Flow Diagrams (DFD) show how data flows around an information system. It is a simple (but powerful) graphic technique that can be used to update and is readily understood by users. Figure 6.1 describes a concept diagram of the current system. A DFD consists of a series of arcs, which join different nodes. Each arc represents a flow of data. They provide information on data flows between external entities and the system as well as internal information on how the data are manipulated. The Data flow in RAMDSS, includes the four basic components: (1) Data collection (2) Data encoding (3), storing and retrieving (4) Result reporter (Figure 6.1) with following the standard entities *Terminator or External Entity, a Data Store, a Process, and Data Flow*. Each entity is discussed in detail below.

6.2.1. *Terminator* or *External entity*

An *external entity or Terminator* is whatever or whoever provides information to the system (or receives information from it). Such information must have (initially) been obtained externally from it. *External entities* or *terminators* are always represented as a rectangle and must contain a name. There are four classes used in the RAMDSS: Spatial Manager (SM), Non-Spatial Manager (NSM), Knowledge Manager (KM) and Decision-Maker (DM).

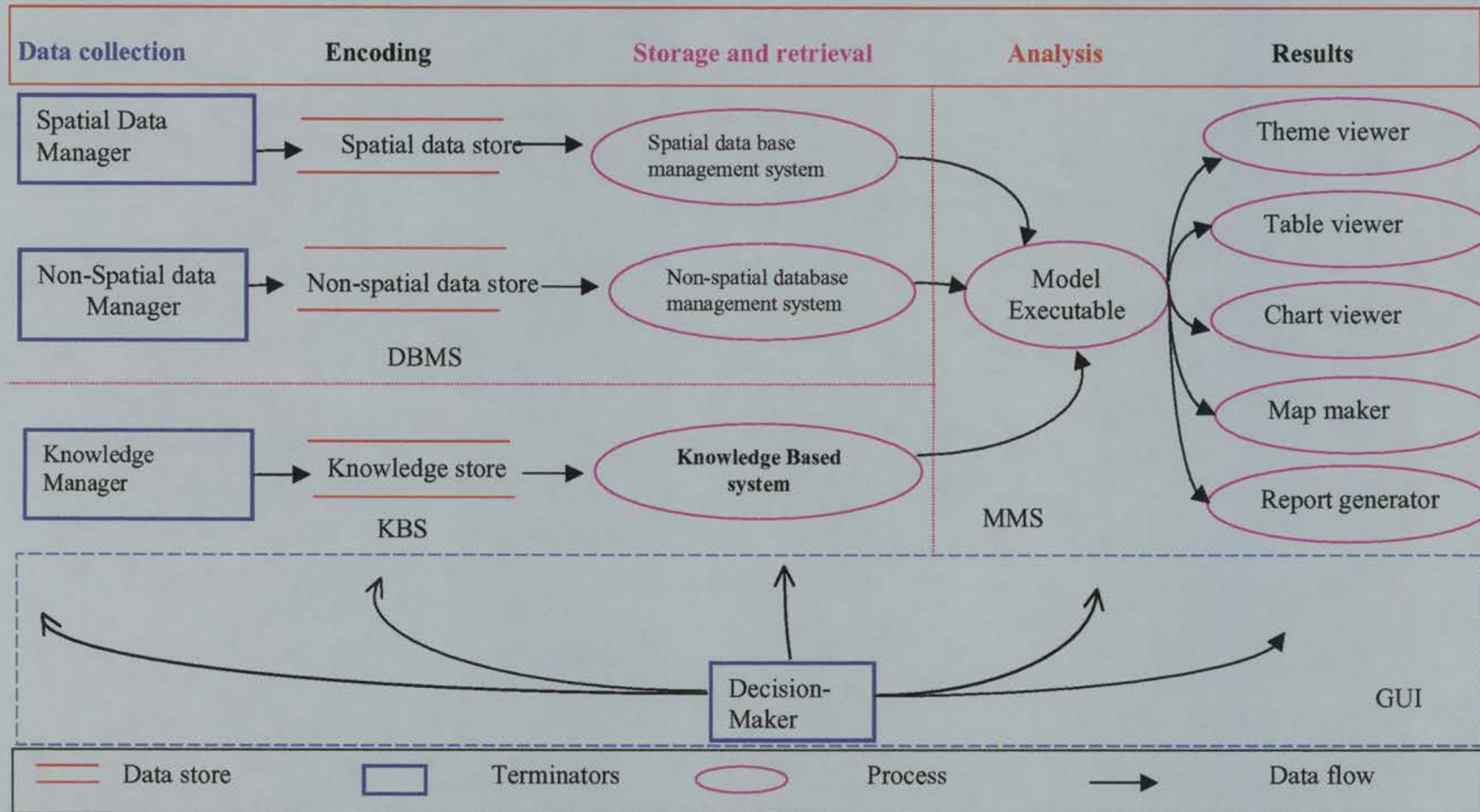
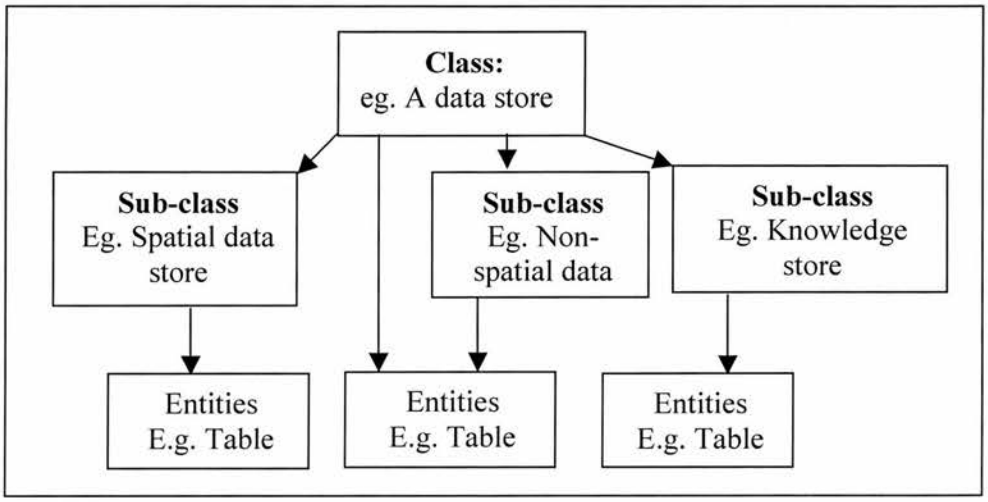


Figure 6.1 an example of an information flow in RAMDSS. The headings along the top indicate the sequential steps in the design, construction and application of the database.

A Class defines a common set of attributes and operations. Class can have a sub-class or entity. For example a Class *Data store* can have either sub-classes such as spatial data store, non-spatial data store, knowledge base store or directly entities. For the detail see below. The role of each class discussed below is relevant to the RAMDSS prototype.



6.2.2.1. Spatial Manager (SM)

The terminator Spatial Manager is the class of RAMDSS, and used for the collection of spatially referenced data. It deals with spatially related entities because the reliable and relevant data to assist in making decisions about where things should be located (or not located) on a landscape or how to manage things that are currently specifically located on a landscape, all data should be geographic in nature, that is data must be linked to specific points, lines, or polygons on a map. These spatially referenced data must also permit the user to build and analyse complex spatial relationships between all three types of data at different scales, degrees of resolution and levels of aggregation.

6.2.1.2. Non-spatial Manager (NSM)

This terminator is the class of RAMDSS, and used for the collection of non-spatially referenced data. NSM handles the data from different sources and also includes the description of all the data source. The data are represented in the form of tables corresponding to entities. For example, the NSM collects and enters the data from socio-economic tables, field data and existing reports and records.

6.2.1.3. Knowledge Manager (KM)

This terminator is a class of RAMDSS, and used for the collection of knowledge or opinion for the specific problem from different sources. The main sources are experienced planners in the field, available policy, records and reports from the Karnataka forest office. The reason for this class is to assist the novice user to improve planning and decision-making.

6.2.1.4. Decision-Maker (DM)

This terminator is the class of RAMDSS, and is responsible for the whole decision-making process. The decision-maker is the user of this system, and in this project is the Range Forest Officer. He/she is responsible for maintaining the spatial manager, non-spatial manager, and knowledge manager for the day-to-day planning process.

6.2.2. A data store

A Data Store is where information is held within the system and is represented as an open box in Figure 6.1. It represents real-world stores of information such as: Computer files, Card indexes, Ledgers, etc. In RAMDSS, the class *data store,* has three sub-classes: spatial data store, non–spatial data store and a knowledge base store. The spatial data store includes location, shape, size, and orientation of the object. The Non-spatial data store (also called attribute or characteristic data) is that information which is independent of all geometric considerations. The knowledge base store is synthesised from the information provided by experts in the field. Each subclass data store is explained in detail below.

6.2.2.1. Spatial Data store

This data store holds detail of the spatial data entities. The structure of this data store is shown in Figure 6.2. Spatial data are geographic data that describe the geometric location of particular features, along with attribute information describing what these features represent. The main spatial entities in this project are metadata and data models (Figure 6.2). There are two fundamental approaches to the representation of the spatial data model: raster model and vector model (Aronoff, 1989). In the raster approach, the units are cells where as in the vector approach the units are points, lines, and polygons (Figure 6.2). Both raster and vector data structure are used in this study. The reasons for using both data structures for this study are given below:

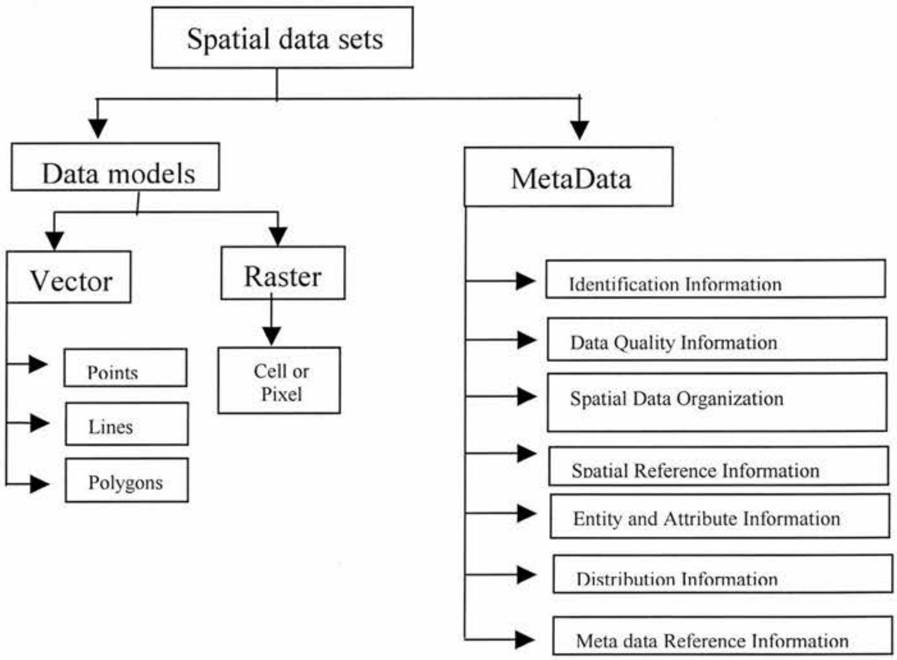


Figure 6.2. Structure of Spatial data sets

The vector model is very well suited to recording the location of discrete geographic features with precise locations like forest roads, forest boundaries, streams, fire watching towers etc. Vector models are suitable for more complex data structure and overlay operations. Raster data record spatial information in a regular grid or matrix organised as a set of rows and columns. Each cell within this grid contains a number representing a particular geographic feature, such as soil type, elevation, land use, slope, etc. Raster data are commonly, but not exclusively, used to store information about geographic features that vary continuously over a surface, such as elevation, reflectance, or groundwater depths. This model is well suited for overlay operations or modelling but the graphical output is less precise than with the vector model. A satellite remote sensing images are a good example of raster data. Knowing the advantages and limitations of the models, both data model approaches were used in this study.

The second entity in the spatial data set is the metadata. Wright and Xiang (1999) describe metadata as "information about data". Metadata is a description of objects, documents or services, which may contain data about their form and content. In spatial data sets metadata stores the information about: Identification, Data Quality, Spatial Data Organisation, Spatial Reference, Entity and Attribute, Distribution and Metadata Reference (Figure 6.2). The metadata was created for all the spatial datasets and stored in the system. As an example, the metadata for the Indian remote sensing satellite based land cover map is given below by taking into consideration the above information (Figure 6.3).

6.2.2.2. Non–Spatial Data store (NSD)

This *data store* holds non-spatial information. NSD sub-class has three entities namely metadata, data types and data block (Figure 6.4.) The metadata entity stores the descriptions that relate to the entire sets used in this *data store*. For example, this could include the data quality, data accuracy, and location details. The data types entity stores the information of different sources of data, for example whether it is from the forest inventory, or socio-economic or existing forest reports and records.

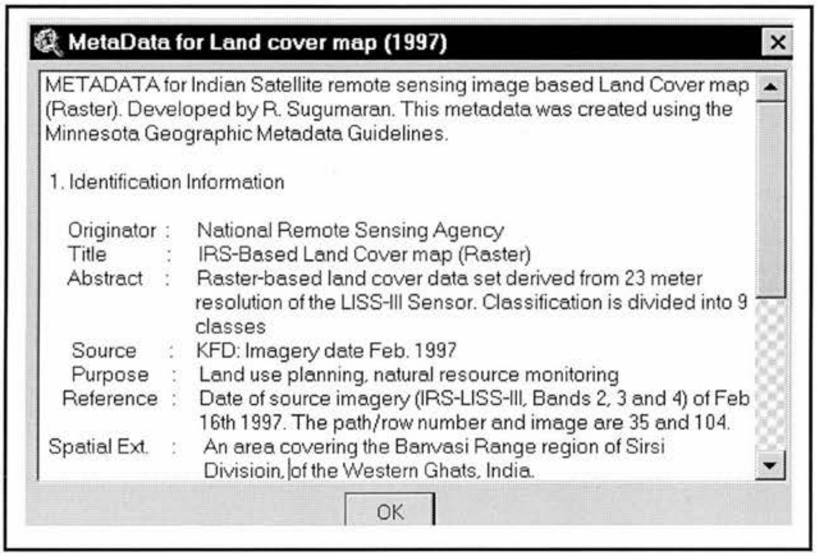


Figure 6.3 Metadata information

The last entity in this data store i.e. the data block section contains the actual values of the various fields for individuals in the stand. The data are represented in the form of tables corresponding to entities. The top-level non-spatial data structure of the datastore is in shown in Figure 6.4.

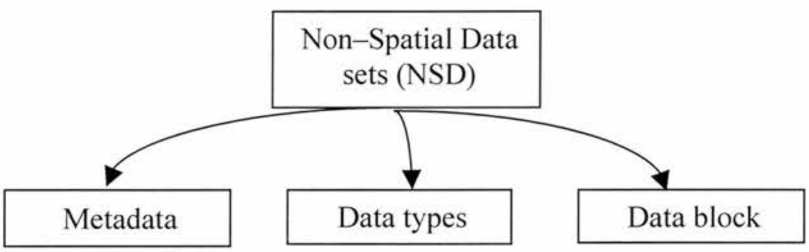


Figure 6.4 Non–spatial data sets structure

6.2.2.3. Knowledge base

The knowledge base holds information about the knowledge sources and knowledge. The knowledge sources entity includes the derivation of knowledge from different sources. For example it may be from the experts, or from the forest policy or from the local people or textbooks. The second entity holds the exact knowledge about the particular problem.

6.2.3. A process

The class *A Process* transforms or manipulates data and presents the results within the system and represented by ovals on a data flow diagram (Figure 6.1). The process description provides the software designer with representation of information and function that can be realised by data, architectural and procedural design (Pressman, 1992). The process may also describe the collected and processed data, needed to develop a model for a particular problem as well as describing the model itself. The model management capabilities are needed to construct, manipulate, modify, analyse, and query data. There are three major entities involved in a process class: modelling, a user interface and result display (Figure 6.5).

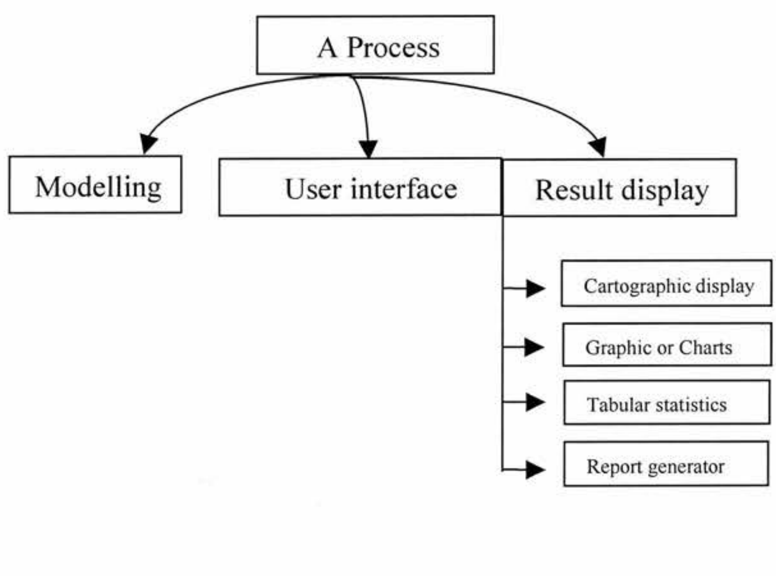


Figure 6.5 A process description in Data Flow Diagram

Modelling assists in the understanding of a process involved and relationship between the variables (Bronsveld et al., 1994). Modelling also helps in analysing the collected data and retrieving the required results from the analysis. One method of model management is to develop a number of analytical sub-routines, which can be stored, retrieved, and linked together to form a specific evaluation model. This allows a large number of models to be made accessible quickly. Another similar method is to develop a model base management system consisting of a number of modules, each of which solves a step in an algorithm. Both methods allow for easy modification and facilitate the adding of new models to the system.

Most models in a DSS allow the user to construct a scenario that reflects the outcome of a particular decision and then evaluate the scenario against the criteria deemed to be important. For example, a scenario could be constructed showing which areas in a forest can be harvested for timber during a specific time period. This scenario could then be evaluated against financial criteria, such as expected revenue, and other criteria such as impact on wildlife habitat, potential for soil erosion, etc. The means of performing these evaluations is the model management system. The model management system uses the data associated with the scenario to be evaluated to parameterise a model or series of analytical models according to specified procedures. All these options should be easy to use through development of a simple user interface.

The second entity i.e. a *user interface,* is the integrating mechanism for the data, models and displays (Figure 6.5). The Graphical User Interface (GUI) is defined as a combination of window, menu, icons selections designed to guide the user quickly and easily through the models. Most DSS users are not experienced planners, although they need the information provided by a DSS. The user interface must allow non-technical users to use the system without a long learning curve. For example, the user interface enables the decision-makers to manipulate, look at the alternatives, run the models, execute the selected model and view the results in an interactive session.

After successful development of scenarios the results can be generated and displayed. The results of the scenario evaluation performed by the model management system must be displayed to the user in a manner that makes the results easy to understand and also easy to explain to others (Figure 6.5). Display and report generators should be capable of cartographic displaying, printing, statistical graphics and tabular data.

The above section, that is the conceptual design of RAMDSS, clearly demonstrates the different classes, subclasses and entities involved in the design through a data flow diagram. The different classes used in the *Data flow diagrams* include: external or terminators, a datastore, data flow and a process. The prototype design of RAMDSS in this section also showed what are the different components and how they can be used within the system. The next section demonstrates how these components are implemented within the prototype.

6.3. Implementation of a Prototype RAMDSS

This section demonstrates how RAMDSS was implemented based on the specification described in the previous section. The following section explores what are the development tools are required. The subsequent section demonstrates how these tools are integrated with different programming languages. The final section explains how the RAMDSS system architecture is developed by a simple easy-to-use interface.

The implementation of the different components mentioned in the conceptual design required different software tools such as a GIS for handling spatial data sets, a Relational Data Base Management System (RDBMS) to cope with large non-spatial data sets, a Knowledge Based System for maintain the knowledge base, and a Graphical User Interface (GUI) for simple user interaction with the system.

The RAMDSS interface combines individual technologies in a single user-friendly computer environment, where each technology can share the data and control the execution of the overall solution process. The RAMDSS system is built primarily on Geographic Information Systems (GIS), and incorporates the tools such as Remote sensing, Knowledge Based Information System, visualisation into a single system (Figure 6.6). How this integration and GUI was developed will be discussed in the final section. The next section explains the advantages of the each tool in the successful implementation of RAMDSS.

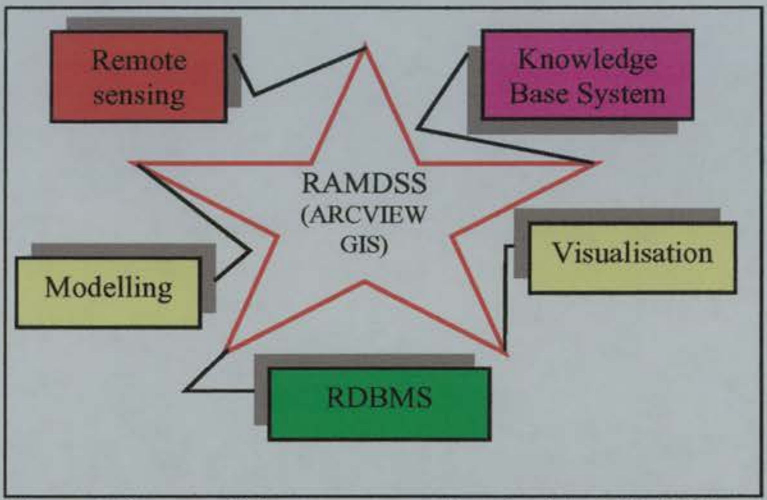


Figure 6.6 some of the components involved in RAMDSS

6.3.1. The RAMDSS Development Tools

Selection of different development tools depends specifically on the availability of the tools in KFD, in order to keep cost down (a user requirement) and also on the availability of trained people within the department. For example, a PC-based ArcView GIS was already installed at the Circle and Range level and other tools such as ERDAS IMAGINE, and ArcInfo are available at the headquarters (Bangalore) where any decision-maker can go and use it. ArcView GIS was selected to develop the prototype RAMDSS, bearing in mind the availability of ArcView GIS at the Range level.

6.3.1.1. Geographical Information System (GIS)

Handling the spatial data sets was performed through a GIS. Arc/info and ArcView GIS were used as GIS software in the study because they are already installed in the study area. Arc/Info (Version 7.1 on Windows NT platform) was used for digitisation, editing and storing all the collected spatial data. The ArcView GIS was used to develop the prototype RAMDSS by customising this software and by coupling with other packages. ArcView GIS has the capabilities to carry out the required tasks in the project which were mentioned in the conceptual design. The major requirements of the system are: it should support spatial and non-spatial database management, it should be easy to use with a powerful user interface, it should support expert opinion for the novice user, powerful display, and modelling capability. ArcView supports most of the requirement such as data base management, simple spatial analysis, powerful visualisation or data display, and also provides the ability to build custom interfaces (ESRI, 1999). Figure 6.7 exhibits the advantages and limitations of the system and an overall summary of

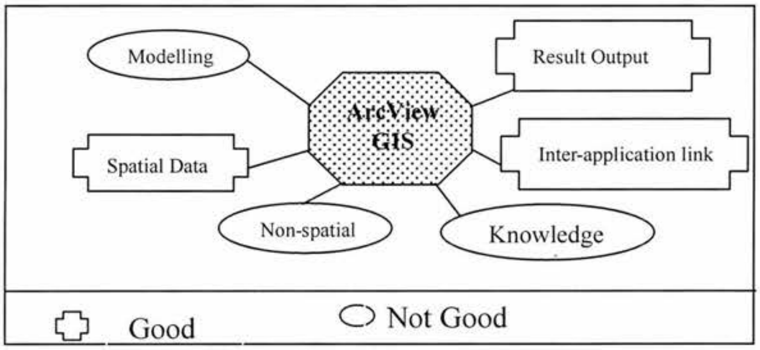


Figure 6.7 Capability of ArcView GIS

the capability of ArcView GIS is given below:

- ArcView GIS is a powerful visualisation tool. It can access records from existing databases (Arc/Info) and display them on maps;
- ArcView supports vector as well as grid based Spatial Modelling and analysis (GSM) (the GSM supported through an extension referred to as 'Spatial Analyst');
- The software presents results and ideas in a straightforward manner because it assists in creating the tables and charts and has the facility to make cartographic layouts;
- It is able to link drawings, photographs, videos and other applications through the Dynamic Data Exchange (DDE), Dynamic Linked Library (DLL), and Open Data Base Connectivity (ODBC);

- It has an image analysis capability which helps in basic image processing through the ERDAS Imagine extension;
- It support different image formats (tiff, gif, jpeg, and Imagine .img);
- It is easy to create reports through the wizard 'The Report Writer';
- It provides the ability to build custom interfaces and dialogs using Dialog Designer;
- It has its own development environment (Avenue programming); and
- It enables the user to create, analyse, and display surface data (through '3-d Analyst' extension).

Although ArcView fulfils most of the user requirement mentioned in the last chapter, it lacks a powerful modelling capability, handling large attribute data set (it only supports dbf, delimited text and info format) and is unable to handle knowledge based information (Figure 6.7). In order to incorporate these options, this systems was linked with other systems through different methods such as ODBC, DDE, DLL, the dialog designer interface and the Avenue development environment.

6.3.1.2. Relational Data Base Management System (RDBMS)

Relational files connect different files or tables (relations) without using internal pointers or keys. Instead a common link of data is used to join or associate records. The link is not hierarchical. A "matrix of tables" is used to store the information. As long as the tables have a common link they may be combined by the user to form new inquiries and data output. This is a very flexible system and is particularly suited to SQL (structured query language). Queries are not limited by a hierarchy of files, but instead are based on relationships from one type of record to another that the user establishes. Because of its flexibility this system is the most popular database model for GIS.

In selecting the RDBMS software in this study, the following criteria were applied: need for an SQL-based Data Base Management System; need to run under Windows operating systems; need to be sufficiently powerful; affordability; and availability of

ODBC extension level. Keeping in mind the above criteria and availability within KFD, Microsoft Access 97 was chosen as a RDBMS.

6.3.1.3. Image processing and Visualisation

Satellite image processing and visualisation was performed using ERDAS IMAGINE (8.3). The major reason for the use of Imagine software is not only because it is installed in the KFD, but also the output from this product is directly supported by ArcView GIS. ERDAS Imagine software is easy to use, fast, and has interactive display and manipulation of popular image data, including satellite image aerial photography, and other remotely sensed data. ArcView GIS also has an extension called 'Image Analysis'. The ArcView 'Image Analysis' is a product of ERDAS and the result of a collaborative effort between ERDAS and the Environmental Systems Research Institute (ESRI) of Redlands, California. In addition, ERDAS IMAGINE also has a visualisation tool namely *'Virtual GIS'*. It allows the user to create 3-D animations with different formats (mpeg, avi and VRML).

6.3.1.4. Knowledge Based System (KBS)

KBS is a computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution (Feigenbaum, 1984). The knowledge based system definitions and descriptions are discussed in chapter 3. There are different declarative programming languages such as CLIPS, LISP and Prolog which are available to represent the knowledge, however in the present study Prolog was selected because of its advantages outlined below.

Prolog is a simple but powerful programming language developed at the University of Marseilles as a practical tool for programming in logic. Prolog is a declarative programming language based on first-order predicate logic. There are various advantages to using Prolog as the basis for a knowledge representation scheme and indeed for many other programming tasks. The major advantages over other programming languages are:

- Prolog is very simple and easy to read (Muetzelfeldt et al., 1989; Guerrin, 1991; Luger and Stubblefield, 1993).
- it supports declarative programming, freeing the programmer from procedural concerns and allowing him/her to concentrate on representing the available knowledge (Muetzelfeldt et al., 1989; Guerrin, 1991; Sterling and Shapiro, 1994).
- it has a modular structure, permitting codes to be changed easily (Luger and Stubblefield, 1993; Clocksin, 1997).
- Prolog is driven by the Prolog interpreter, an 'engine' that includes powerful built-in symbolic manipulation and reasoning facilities including backtracking and unification (Guerrin, 1991; Clocksin, 1997).
- Prolog is highly extensible and provides the facility to write meta-level code so that programmes can be written to modify other programmes, thereby extending the basic inference mechanisms provided by the Prolog interpreter (Muetzelfeldt et al., 1989; Luger and Stubblefield, 1993; Sterling and Shapiro, 1994; Clocksin, 1997).
- as a form of first-order logic, Prolog is applicable to any problem domain, satisfying all the basic requirements needed by a general purpose representation formalism (Moore, 1982).
- With dynamic linking, the foreign resource can be linked and un-linked to other applications (This option helps linking to ArcView, which also supports dynamic linking)

There are several textbooks available providing excellent treatments of both the theoretical and practical aspects of Prolog and of declarative or logic programming (Clocksin and Mellish, 1994; Sterling and Shapiro, 1994). For the working programmer, Clocksin (1997) provides a more practical text designed to quickly and effectively introduce the reader (who is assumed to have programming experience) to the basics of the language. Realising the importance of Prolog: its simplicity, and its capability to provide dynamic linking (compatible with the ArcView requirement) with other applications, it was decided that Prolog should be used in the prototype.

6.3.2. Inter–application communication

In order to develop an appropriate DSS, the available tools should be integrated. In this project, a Data Base Management System, Modelling capability, a Knowledge Based System, and user interface, display and report generator were put together and a prototype was developed (see chapter 5). Although ArcView GIS fulfils most of the requirements for the development of a DSS, for example, DBMS, image processing with *'Image analyst'* extension, simple modelling (through *'spatial analyst'* extension), and report generator through *'report writer'* extension it lacks the capability of handling a knowledge base, a powerful in-built modelling capability and capacity to handle large non-spatial, complex data sets. In order to link the Knowledge Based System, RDBMS and ArcView and provide a more and complete modelling capability, different methods were used, which are discussed below.

The major linking process involved in this project is a client-server approach. In this approach one application establishes itself as a server and then other applications become clients by connecting to the server. The client request services from the server application. The server performs those requested tasks in response to the client requests. The Client/Server relationship allows you to share functionality among multiple processes and to distribute functionality across multiple machines (ESRI, 1999). In order to make the link between applications, ArcView provides several different means for communicating with other applications. ArcView supports three kinds of client/server interaction. The communication protocols of ArcView GIS are through DLL, DDE, and ODBC. On Windows, ArcView supports DDE interaction and can call procedures and functions from a shared library or dynamically linked library (DLL) (Figure 6.8).

As mentioned earlier ArcView (3.1) integrates different application software such as 'report writer' (for report generation), spatial analyst (for raster data analysis), Imagine (simple remote sensing image analysis) and 3-D analyst (for visualisation) (Figure 6.8). However, the present system does not support modelling and Knowledge Based System. The linking of these components was achieved through different coupling methods. The major integration includes ArcView-Sictus Prolog link, ArcView-MS-Access link, and ArcView-Modelling link (Figure 6.8). The following section explains in detail how these links were achieved.

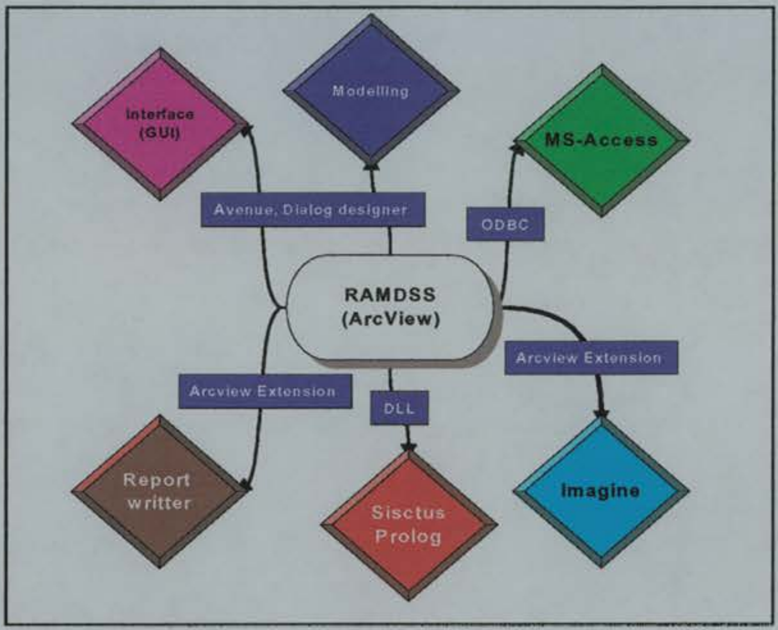


Figure 6.8 Intercommunication application

6.3.2.1. ArcView-Access link

ArcView GIS has three ways of linking to any Relational DataBase Management System. They are DDE, DLL and ODBC. In this study ODBC functionality, which is available within ArcView was chosen. ODBC stands for Open Database Connect and is a Microsoft specification. ODBC provides a standard way of defining data sources and their data access methods. The reasons for this choice: the limitations of other methods such as DDE and DLL available within ArcView system. The major drawback with DDE and DLL in handling the table is that it duplicates the data from the sources and stores it permanently in ArcView. A DDE approach is less defined and may require more complex code and DLL provide functionality for communicating at a lower level than ODBC and DDE, where a programme must be written specifically to access the functionality available in DLL. The ODBC connection translates requests from a client application by defining a common interface for communication to the server. The simple architecture for an ODBC is illustrated in Figure 6.9.

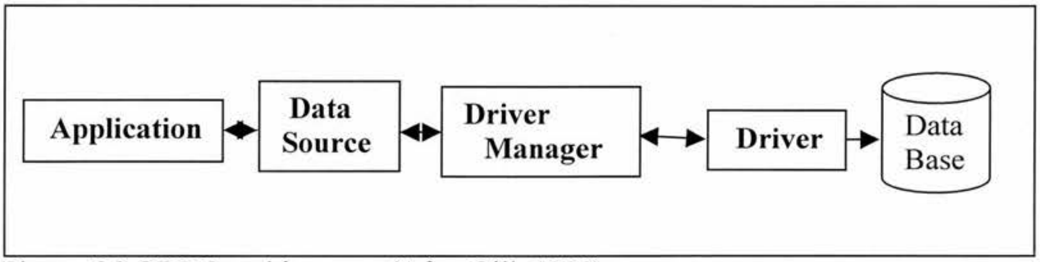


Figure 6.9 ODBC architecture (After Gill, 1998)

In order to connect to SQL databases, the Microsoft Windows versions of ArcView uses Microsoft's ODBC (Open Data Base Connectivity) standard. ODBC is Microsoft's open interface for accessing data in a heterogeneous environment of relational and non-relational database management systems. Firstly, install an ODBC driver for the database, then use the ODBC Administrator to configure a data source for the database (Figure 6.9). ArcView supports any database for which you have an ODBC driver and any necessary database client software (ESRI, 1999).

6.3.2.2. ArcView and Modelling link

ArcView does not have any powerful modelling capability (Figure 6.6). Although, recently, the 'Spatial Analyst' was introduced as an extension in order to explore the spatial relationships, the modelling capability was not available when this project started three years ago. However, the present 'Spatial Analyst' is able to perform only the simple functions such as Find Distance, Assign Proximity, Calculate Density, Cell Statistics, Summarise Zones, Histogram By Zone, Tabulate Areas, Map Query, Map Calculator, Neighbourhood Statistics, and Reclassify. Furthermore, users should have the detailed experience in order to use the 'Spatial analyst' extension effectively. Keeping these issues in mind and also to achieve user specified modelling, dialog designer and avenue programming and the 'spatial analyst' extension available within the ArcView application were used. Several user models were built using dialog designer such as plantation models, non-forest timber forest produce model, protection model etc. Figure 6.10 shows the model interface developed using dialog designer and avenue programming.

The ArcView Dialog Designer is an extension to ArcView GIS that provides Avenue developers with a new tool, a dialog, to customise ArcView's interface. Dialog Designer allows the user to create specialised input forms to organise related tools in separate dialogs. By adding buttons directly to your view or layout, it is possible to link what is displayed in a dialog directly to data (ESRI, 1999).

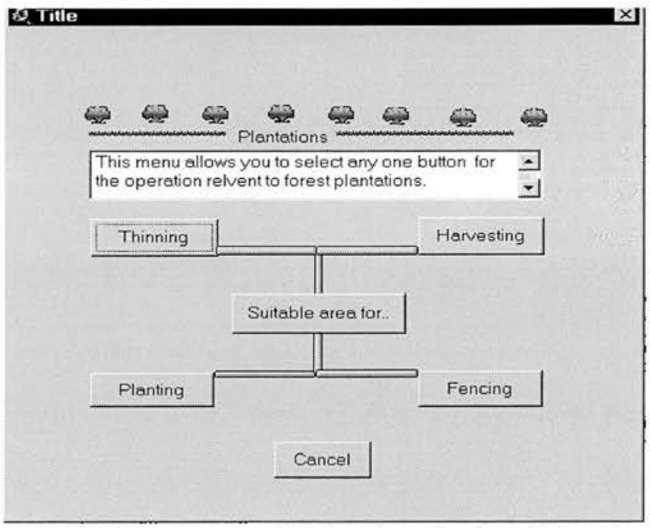


Figure 6.10 Plantation model developed using dialog designer

Avenue is an object -oriented programming language and development environment that is part of ArcView. Avenue is fully integrated with ArcView and runs on any of the platforms for which ArcView is available. There are many uses for Avenue: to customize, to perform a specific task to develop a complete application that works along with ArcView's graphical user interface (ESRI, 1999). The combination of these two functions give the developer the opportunity to provide the level of functionality required for a large part of the total user requirement in a manner which minimises the need for user expertise with ArcView.

6.3.2.3. ArcView and Sicstus link

The link between the ArcView and Sicstus was achieved through the Dynamic Link Library (DLL). A library is a compiled collection of procedures (or functions) that you can call from another application. Libraries are used to store procedures that are called frequently, eliminating the need to code the same procedures in every application that uses them. When a library is used it must be linked to an application. There are two kinds of libraries, static libraries and dynamic libraries. Static linking occurs at the time of application compilation. In other words, static libraries must be linked with the executable itself at the time the executable is compiled. Whereas a dynamic-link library is an executable module that contains functions other applications can use to perform tasks. DLLs are linked to an application at run-time, not at compile time, as occurs with static libraries (ESRI, 1999). The advantage of DLLs is that you can extend the functionality of an application without recompiling the original executable, by dynamically loading modules. ArcView provides classes and requests, which support loading DLLs, and the calling of procedures in these types of libraries.

In this project, custom DLLs were created that perform specific tasks using the C++ programming language in order to integrate ArcView with Sicstus Prolog (Appendix 1). Functions in DLLs can be called directly from Avenue, and data can be passed back and forth. The DLL and DLLProc classes in Avenue provide support for loading a DLL and making calls to its functions. Functions implemented in the DLL are called by creating an instance of the DLL class, then creating DLLProc instances for each function, or procedure, in the DLL call. These instances can then be called to perform the DLL function. When a DLL object is created, the DLL is loaded into memory and is ready for use. When the object is destroyed, the DLL is unloaded and the memory freed. There are four basic steps to executing functions in a DLL: 1. Create a DLL, (2) Load the DLL using DLL.Make (3) Use DLLProc.Make for each function (or procedure) in the DLL and (4) Use DLLProc.Call to call the desired DLL function (ESRI, 1999). The example for the four steps followed in the Avenue programming is showed in the Figure 6.11.

```
' Name: Select_button to interact between ArcView and Sisctus Prolog
'
' Author: R.Sugumaran
'
' Date: 02/01/98
' Purpose: It links the Sicstus with ArcView using DLL which is created using Microsoft  C
programming
' Returns :

' Open the DLL & get a handle to the function
SicsDLL = DLL.Make("sics_dll.dll".asFileName)

' Load the DLL using DLL.Make
_querySicstus = DLLProc.Make(SicsDLL, "sicstus_processQuery",
#DLLPROC_TYPE_STR, {#DLLPROC_TYPE_STR, #DLLPROC_TYPE_INT32})

_queryState = DLLProc.Make(SicsDLL, "getState", #DLLPROC_TYPE_STR,
          {#DLLPROC_TYPE_VOID})

' Initialisation
result = String.MakeBuffer(2048)

current = ""
reset = 1

'Call the DLL to retrieve the results
result=_querySicstus.Call({current, reset})
_title=_queryState.Call({})

' Extract a list from the string result
_list_results = List.Make
_list_results = result.AsList

av.getProject.findDialog("Dialog1").open
```

Figure 6.11 Avenue example

Linking with other applications such as image processing software ERDAS IMAGINE was directly supported by ArcView software through an extension called *'Image analyst'*. *Virtual GIS* from ERDAS IMAGINE has been used as a visualisation tool. Although recently ESRI produced *'3-D Analyst'* as a visualisation tool in ArcView GIS, because of non-availability of this extension in the project, '*Virtual GIS*' from ERDAS IMAGINE was used. Different 3-D animation has been created using '*Virtual GIS*' in this study. For example, a fly-through model (3-d animation) was generated and saved as avi format. These animations can be read directly from ArcView through an interface written in Avenue. The future study will use the '*3-D Analyst*' as a visualisation tool in RAMDSS. The above sections demonstrate how different software have been coupled and used within RAMDSS. The next section explains how a modified interface was developed using Avenue, which reflected the user requirements.

6.4. Interface development in RAMDSS

Having identified the need for a DSS, the main aim of the project is the development of an appropriate DSS with a simple interface for the forest ranger in order to assist in the decision-making processes. Realising the importance of the user requirements, which were discussed in the chapter 5, ArcView was customised using Avenue programming. ArcView's main or parent window was customised, and buttons added and menus placed on the tool and menu bar respectively. Based on the user requirement, there are four main modules. These are the *Data Manager*, the *Production Manager* and, the *Protection Manager*, and the *Display Manager* (includes Mapmaker, and Report generator) and have been added to the main window. This customised main window is show in the Figure 6.12.

6.4.1. General features of the modules

Before giving a full description of each module, it is worth explaining the important terminology used in this section. The terms menu, menu bar, button and tool bar, main window, dialog box, command, and module have been used (Figure 6.13). The main window is the full screen, which posses all the tools such asa toolbar, a menu bar and a status bar. The pull-down menu bar is a special toolbar at the top of the screen that contains menus such as data manager, production manager, and help (Figure 6.13).

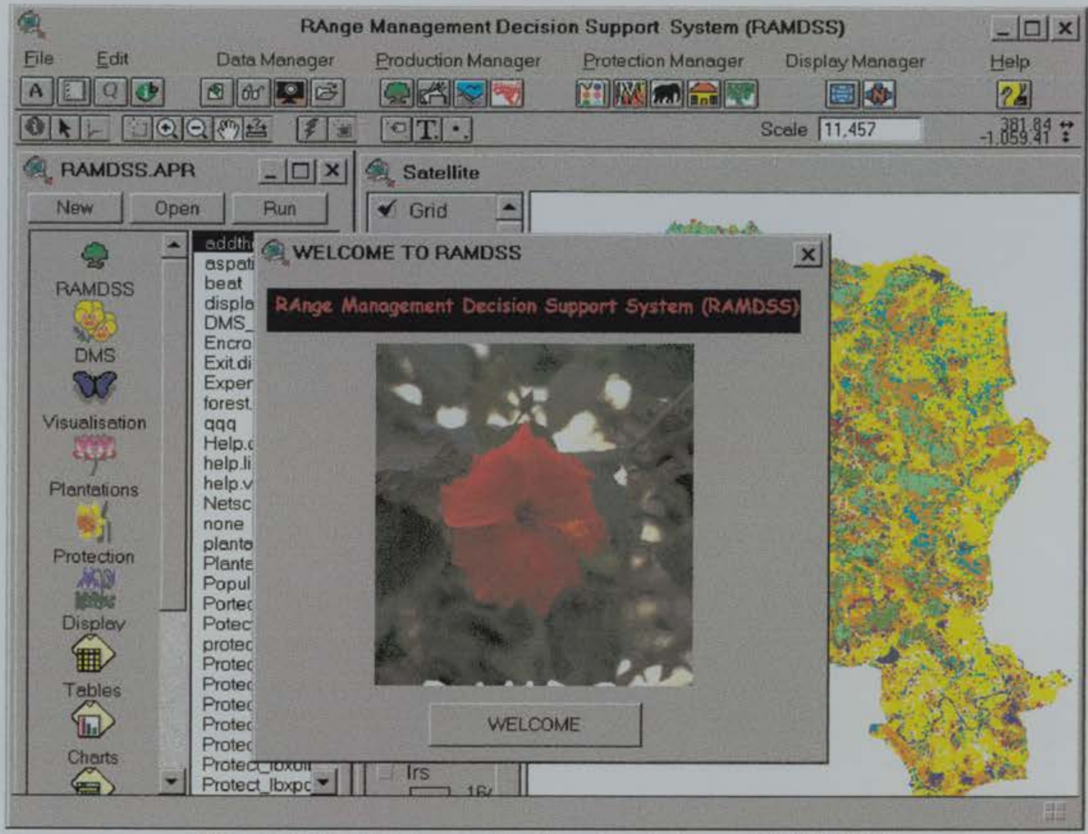


Figure 6.12. The customised main window of RAMDSS

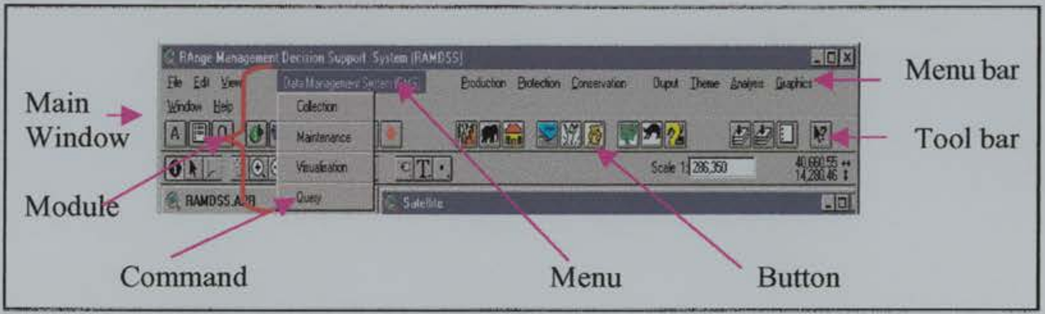


Figure 6.13 Terms used in the modelling process

This pull-down menu bar helps the user to select a command and run a particular model. A menu displays a list of commands and entire command and menu called a module. Alternatively, the button bar is a special tool bar below the menu bar with relevant buttons which also has the same functionality on the menu bar but it helps the user to interact with the system easily (Figure 6.13).

6.4.2. Modules in RAMDSS

6.4.2.1. Data Manger

Data Manager is one of the important modules in the RAMDSS. In order to take timely and effective decision-making process requires up-to-date, and accurate data collection from different sources (Wright and Xiang, 1999). After collecting relevant data they need to be maintained for planning purposes. In order to fulfil both the user requirements and manage the data sets, there are four commands: such as *data collection*, *data maintenance*, *data query* and *data visualisation* which have been provided in the pull-down menu of the Data Manager module on the main bar (Figure 6.14). The role of each command is described in detain below.

Figure 6.14 Data manager module in the main window

The ***data collection*** command allows the user to add new spatial information (mainly shape format, Arc/Info format, Imagine format, and AutoCAD format) or non-spatial data (dbf, Info, delimited text and MS-Access format) from the different sources into the system. The ***data maintenance*** function gives the planner an easy way to modify or update both the spatial and non-spatial database. Once the user selects the ***Data maintenance*** function from the DM menu, it allows the user to choose either the spatial or non-spatial data sets for the purpose of editing the database. ***Data query*** command affords a browse facility through the existing data sets. The major use of this function is to give the user the opportunity to explore the existing data sets and ask simple queries of the existing data. It uses both an in-built query builder available in the software (Figure 6.14) and also interface developed using avenue programming to query and view the existing database (Figure 6.14).

The final command in the ***Data Manager*** is ***Data display / Visualisation***. Visualisation is a form of communication which is universal, and which has the ability to form an abstraction of the real world into a graphical representation which is comprehensible to a wide range of people (Loh et al., 1992). Much of the data stored in the system is designed to provide such an abstraction and the user requires tools to translate that abstraction into an intelligible representation. Traditional methods of representation (maps) as well as new methods (3-D animations) are provided. These are coupled with visual aids (video and images) into an integrated visualisation tool which can not only help newly posted forest planners familiarise themselves with their range more efficiently but also give more experienced planners the opportunity to visualise the result of queries of the database.

6.4.2.2. Model manager

One of the values of any DSS lies in the assistance if offers to the planners in examining different strategies to address a particular problem (Fedra, 1995). This objective was achieved in this module. Several models have been developed in order to support the planners in decision-making. The requirement for these models were collected during the interview conducted with forest personnel. After collecting the requirements each model was grouped into one of the two major groups or modules: production and protection. These groupings were based on the income (Production) and expenditure (Protection) of the forest. The descriptions for these modules are discussed below

6.4.2.3. Model Manager (Production)

The Production module helps the user to find out the areas suitable for the generation of revenue from the study area. This module allows the user to run different models and view the alternatives before taking the final decisions. The module includes identifying the areas suitable for collection of Dead and Fallen timber, Non-Timber Forest Produces (NFTP's), and harvesting of plantations (Figure 6.15).

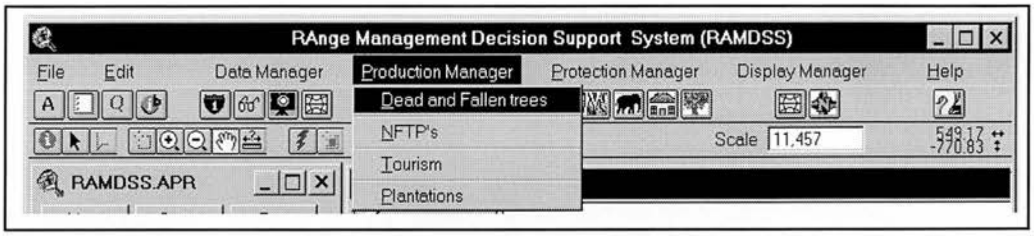


Figure 6.15 Production module in the Model Manager

6.4.2.4. Model Manager (Protection)

Forest protection and management is one of the major activities carried out by the RFO's in KFD. The protection module assists the user to select suitable models from the menu bar and analyse for effective protection. The interface developed for this module is shown in the Figure 6.16. The module includes: ***Encroachment*** (To find out areas with encroachment problems), ***Fire*** (To select suitable areas for fire protection), ***Grazing*** (To identify areas which need grazing protection), ***Soil*** (To choose areas which need soil protection), ***Joint Forest Planning and Management*** (JFM) (to select areas for the development of JFPM), ***Wild life*** (to identify areas for wild life conservation), and ***Medicinal plants*** (to identify, locate, and conserve medicinal plants).

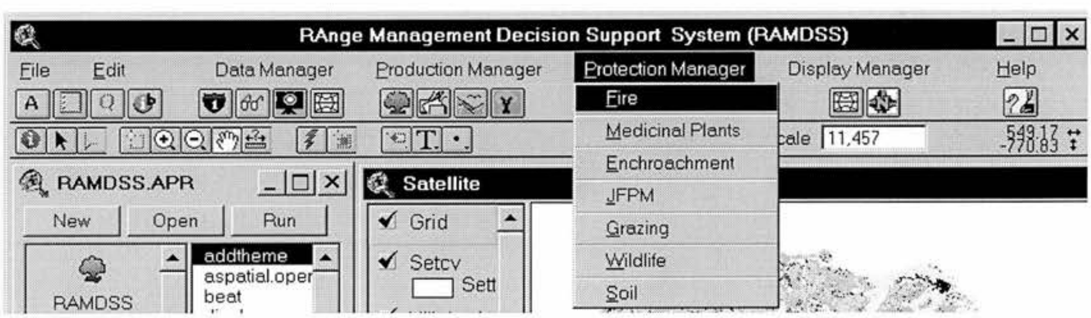


Figure 6.16 Protection module in Model Manager

6.4.2.5. Display Manager

The main aim of this module is to provide planners with a simple, semi-automated method of producing a printed output of query and modelling results in maps as well as a report form. These options were included in the system by adding two commands to a ***Data Manger module***: ***Mapmaker*** and ***Report generator*** (Figure 6.17).

Figure 6.17 Display manager in the main window

The ***Mapmaker*** command assists the user in easy production of maps. After analysing the required model, then user can use the ***Mapmaker*** to produce a neat layout and to take a printout. The second command ***Report generator*** allows the user to make automatic reports using the crystal reporter.

6.5. Summary

This chapter is a continuation of the last about the development cycle. In the previous chapter, the collection of user requirements in the development cycle was discussed (Figure 5.1). In this chapter, conceptual design for the development of the prototype RAMDSS was amplified. The conceptual design was explained with the help of data flow diagrams. The data flow diagram used four external entities or terminators, namely spatial data manager, non-spatial manager, knowledge manager and decision-maker to denote information to the system. Then implementation of the prototype was attempted based on the conceptual design developed. The implementation stages in this prototype include selection of different development tools, integration of these tools into a single system. The final section explained the user interface developed and their role in decision-making. The next chapter will demonstrate the data collection and processing from the study area.

Chapter 7: Data collection and processing

User requirements and conceptual design were discussed in the previous chapters. This chapter describes how different data were collected from the study area and processed for the analysis. The section 7.2 describes the nature, and reliability of the relevant data collected from different sources. The sections 7.3, 7.4 and 7.5 describe the spatial database collection which includes land use/land cover data from the remote sensing image, soil, geology, administrative boundaries, forest type and forest density, non-spatial data and knowledge base respectively. The data processing is outlined in section 7.6. The next section discusses some of the important issues.

7.1. Data requirement for the development of RAMDSS

Collection of reliable and relevant data is one of the key steps in any decision support system (Huxhold and Levinsohn, 1995; Wright and Xiang, 1999; Greening and Gilbert, 1999). In order to make effective decision-making, accurate, precise, relevant and accessible information are required. It is at the data collection stage that these criteria may be filled. In order to collect data, a field visit was made to the Western Ghats, during the period from June 1997 to November 1997. In the first month, lengthy discussions were held with forest officials from the Karnataka Forest Department in order to understand the existing planning process but also the different data available within the department. Then the data were collected from different sources, for example, the forest department, the soil and land use planning unit, and Regional Remote Sensing Service Centre (RRSSC). The major user requirements from the RAMDSS are to be able to collect the data from different sources efficiently, storing, and analysing the data. Keeping this in view, different data such as spatial and non-spatial information, which includes field data, socio-economic data and expert knowledge from different sources were collected (Chapter 5).

7.2. Data collection and validity

In order to understand and to take appropriate decisions on the complex processes involved in forest land planning and management, a range of ecological, environmental, social and economic data is required (Susilawati and Weir, 1990). Ideally, the data for forest management needs to cover both spatial and non-spatial information, and demands the acquisition of many kinds of specialist knowledge and techniques from various related disciplines (Sharifi, 1992; Puttee, 1989; Funnpheng et al., 1994; Susilawati and Weir, 1990). Collection of existing data from multidisciplinary fields suffers from many constraints such as different scales, collection for different purposes or different levels of accuracy (Aspinall et al., 1993; Hall, 1995). Validity of these collected data is another important issue in data collection. Hall (1995), explained that data collection in the developing countries is one of the main bottle–necks, especially the issues of accurate or precise data. In order to develop the prototype RAMDSS, the data collection was grouped into three sub types based on the nature of the information:- (a) spatial database (b) non-spatial data base and (c) knowledge base. The data collected from the different sources are described in detail below.

7.3. A spatial data

A spatial database is one of the important requirements for the development of any DSS based application, since any planning involves some geographical reference. In the present study all the available and reliable thematic maps covering information considered vital to management were collected. Forest land cover and land use maps, soil, geology and geomorphology maps are some of the examples. The next paragraph explains the character of the different thematic data used in the study.

7.3.1. Land use and Land cover maps

Land use and land cover maps are important in any planning activity because of their rapid changes. Land use has been defined as "human activities which are directly related to the land" (Clawson and Stewart, 1965), whereas land cover describes " the vegetational and artificial construction covering the land surface" (Burley, 1961). The Land Use and Land Cover (LULC) data files describe the vegetation, water, natural surface, and cultural features on the land surface. In this study, remotely sensed imagery was used to collect land cover information because of rapid mapping and updating capability. The detail of the satellite image used and its description is discussed in the next paragraph.

The most suitable satellite image data are at this moment are derived from Landsat TM, SPOT, and IRS-1C images. In the present study, the Indian Remote Sensing image (IRS 1C LISS-II) was used because of its better spatial resolution compared with other satellites (Table 1). A detailed description of the satellite data is given in the Table 7.1. The extracted image for the study is from the main scene, with a False Colour Composite (FCC) generated using Bands 2 3 & 4 as shown in the Figure 7.1.

Table 7.1 IRS-1C satellite image description

Sensors	Bands	Wavelength (μ)	Resolution (m)	Swath (Kms)	Repetition
Panchromatic	1	0.50 - 0.75	5.8	70	5 days
LISS-III*	1	0.50 - 0.59	23.5	70.5	5 days
	2	0.62 - 0.68	23.5	70.5	24 days
	3	0.77 - 0.86	23.5	70.5	24 days
	4	1.55 - 1.70	141	148	24 days
WiFS **	1	0.62 - 0.68	188	770	24 days
	2	0.77 - 0.86	188	770	24 days

*LISS – Linear Imaging and Self-Scanning; **WiFS – Wide Field sensors) (Source: NRSA report, 1995).

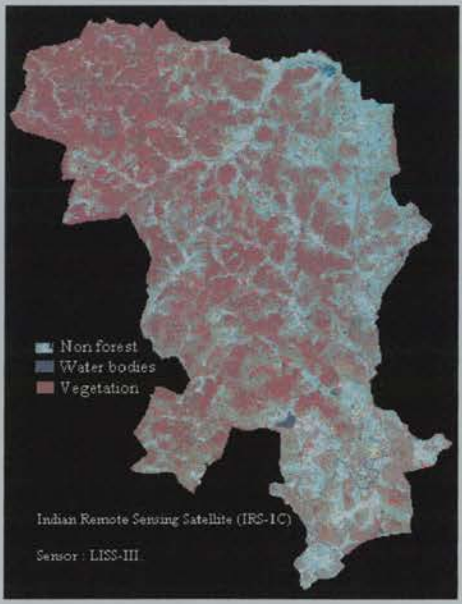


Figure 7.1 False Colour Composite generated from the IRS data.

The satellite (Indian Remote Sensing Satellite IRS -1C) image was acquired on February 16, 1997. The main reason for the selection of February was due to it being cloud-free and evidence from earlier research (Unni, 1993; Sugumaran, et al., 1994b; Sugumaran, et al., 1994c). Although there are several land use maps available for the study area, (for example the Pascal map at 1: 1000000, Pascal, 1994; the National Remote Sensing Agency map at 1: 25,000), in the present study three land use maps:- 1. Forest survey map 2. Forest land use and 3. Village maps were used. The main reason for not using other existing maps is due to the fact that these maps are either large scale or outdated or of less accuracy. The forest land use map (at a scale 1: 14,800) of Banavasi Range was used, because of its higher accuracy. The forest survey map was obtained from the Survey of India topo-sheets (SOI) at 1:50,000 scale. The 1: 6000 scale set of village maps were collected from each village office. A detailed description is given in the Table 7.2.

7.3.2. Administrative boundaries

Administrative boundaries such as village, beat, section, and range (the hierarchy is discussed in detail in chapter 3) were collected from the existing Forest Survey Maps with scale of 1:15,400 (Table 7.2).

7.3.3. Topographic maps

This category includes collection of contour map, benchmarks, water bodies and settlements. These data were directly traced from existing SOI maps (Survey of India topo-sheets numbered 46 J/9, 12, 13, and 14) and converted using Arc/Info software. Then using contour, canals and benchmarks, a Digital Terrain Model (DTM) was generated using the Arc/Info Tin module. Finally, themes such as slope, aspect and elevation were derived from the DTM.

7.3.4. Soil, Geology and Geomorphology maps

The soil map at the scale of 1:250,000 was collected from the Indian Soil Survey and Land Use Planning Unit. Geological and Geomorphological data were collected from Geology Survey of India (GSI, Bangalore) as hard copies (Table 7.2). The reason for the use of large scale maps of geology and geomorphology (1:1 M), was simply because of the unavailability of detailed maps for this area.

Table 7.2 Spatial information collected and used

Themes	Scale	Source
1. **Land use /cover** Forest land cover map Forest land use maps Forest Survey Maps Village maps	1:50000 1 : 15,400 1: 15,4000 1 : 6,000	State Remote sensing center (1997) Karnataka Forest Department (KFD) Forest Survey Maps (1884) " KFD source (1884)
2.Administrative boundaries Range, Sections, Beats and Villages	1:15,400	KFD Forest Survey Maps (1884)
3. Topography Contours, Benchmark Settlements Slope and aspect DTM Water bodies	1 : 50,000	Survey of India (SOI) topo-sheets (1972)
4. Soil	1.250,000	Soil survey and land use planning unit (1995)
5.Geology and Geomorphology	1:1000000	Geological Survey of India (1988)
6. Infrastructure Roads Canals Fire tower location Check posts	1: 50, 000	Survey of India topo-sheets (1972)

7.4. Non-spatial data

The collection method for non-spatial data included questionnaires and extensive field survey. The questionnaires were used to collect forest inventory data and village socio-economic data (Table 7.3). The questionnaires were distributed to all the villages and information was collected through State Forest Department Officials. In addition, existing reports and records were also used. The detailed questionnaire is given in Appendix 2. The questionnaire describes in detail the nature of the different data and different data types. Further, personal interviews with forest managers (Rangers, Divisional Forest Officer (DFO) and the Conservator of Forests (CF)) were also carried out to collect information on how a DSS might help in decision-making and what sort of assistance might be required from a DSS.

Table 7.3 Non–spatial data collected for the study

Forest Inventory data		**Socio–economic data**
Regeneration	Medicinal plants	Administrative structure
Fire Incidence	Special privileges	Local organizations
Infrastructure	Forest types	Population statistics
Plantations data	Forest conditions	Land holdings
Encroachment	Nursery data	Literacy
Non forest timber	Video coverage	Offence cases
Eco-tourism	Logging Extraction	Livestock
Photographs	Tree species	Local people consents
Urban fuel wood	Village committee	Wood saving devices

7.4.1. Forest inventory data collection

Extensive field study was carried out during the second year of research. The main aim of the field study was to collect data on forest vegetation information (detailed below) from different forest types, Ground Control Points (GCP) for the satellite image processing, village socio-economic data, images and video coverage to build visualisation models and the decision support models. The field survey was carried out with a team of 15 people from the Karnataka Forest Department officials. The field team included a taxonomist, photographer, District Forest Officer, Survey Ranger, Ranger, and twelve beat guards and many village guards (Figure 7.2).

Figure 7.2 Field team members for the data collection

The survey group was divided into several teams. (a) *Preparation team:* The main job of this team was to make a clear path for transect studies (b) *Tree measurement team:* This team's job was to collect the information on tree measurements, made in the field (c) *Regeneration team:* counted saplings in the plots (d) *Collection team:* collection of plants and soil in the study area, and (e) An *Expert team:* included an experienced taxonomist from the area, local experts and forest officers for the identification of plants by their local names and taxonomical names. The detailed description of data collection is given in the next section with an explanation of what sampling method was adopted and how data were collected.

7.4.1.1. Sampling method adopted

In order to undertake sampling, a reconnaissance survey was conducted with the help of forest officials and existing forest survey maps. Then a stratified sampling method was used for different forest types such as semi-evergreen, moist-deciduous and dry-deciduous forest. Thirty-three sample plots were laid in order to obtain a representative sample of the floristic variation of the study area using different vegetation types (Figure 7.3).

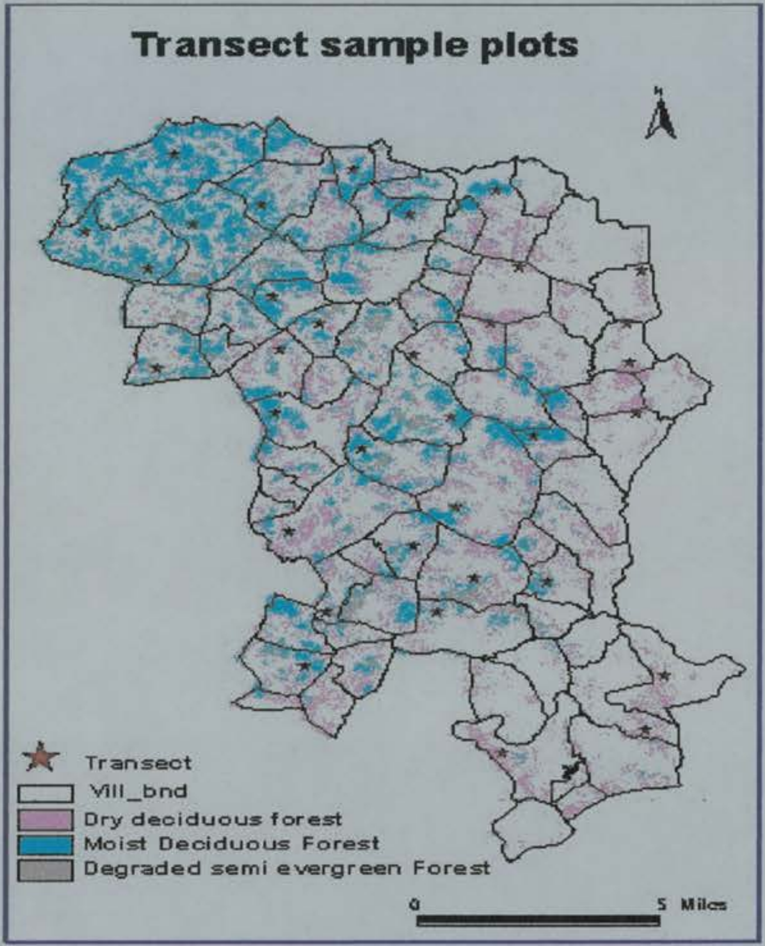


Figure 7.3 Sample plots location in the study area

The procedure adopted in this study is a standard method used in by the Karnataka Forest Department (KFD record, 1995). A belt transect method with a standard of 240 meters length was adopted in this study to collect the data. A diagrammatic plan of the vegetation plot established at each site is shown in Figure 7.4. A sample plot in the forest patch (mentioned as polygon in the Figure 7.4) was established in all the three main forest types. All the measurements were carried out within the buffer of 20 metres (Figure 7.4). The data collected within the buffer is explained in the following paragraph.

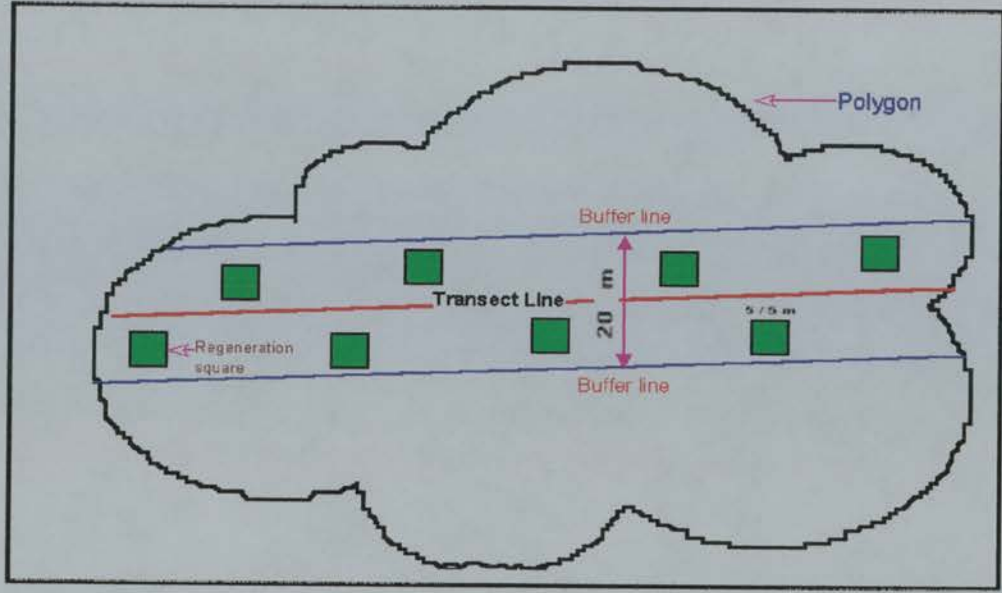


Figure 7.4 Data collection in the field using a belt-transect method (Source: Karnataka Forest Department)

7.4.1.2. Data collection along the line transects

Tree measurement consisted of collecting data on all the tree species greater than or equal to 10 cm girth occurring along the transect line. The measurements included GBH (Girth at Breast Height or 1.30 m), height of the tree and total number of the trees. At the same time, plants were identified (both botanical and local name) in the field with the help of a taxonomist expert. In addition, along each transect, the regeneration status of the tree species was also counted by making 5 * 5 metre plots. Further, in order to generate visualisation tools, video coverage and photographs were also taken in the study area.

7.5. A knowledge base

In order to collect the knowledge for the Knowledge Based System, information was collected from different sources. Intensive interviews were undertaken in order to collect the information. The major source of information was from the local villagers, experienced foresters, retired forest officials from the study area and experienced taxonomists from the area. In addition, different forest policies, forest department reports and records and textbooks were also consulted to build a comprehensive knowledge base (Thakur et al., 1989; Sharma, 1993; Vaidyaratnam, 1993; Sivarajan and Indira, 1994; KFD reports, 1995; Heywood, 1996; Yoganarasimhan, 1996).

After collecting the extensive available data from the study area, the raw data were processed using different software available. The detailed data processing of the spatial, non-spatial and knowledge base is described in the next section.

7.6. Data processing

The data processing involves conversion of raw data into a format useful for the analysis. The data conversion includes the digitisation of hard copy maps,processing of satellite images, entering the non-spatial data into a database, and storing the knowledge base into the Knowledge Based System. In addition, detailed metadata was prepared for all the data and grouped into: spatial data conversion, storing the non-spatial data and elicitation of knowledge base. The following section explains each process.

7.6.1. Spatial data conversion

This category involves conversion of the existing spatial data (hard copy maps) into digital form and the processing of the satellite image. The first section explains how methodology used in satellite image processing and second section demonstrates how the digitisation was carried out for the raw data conversion. The final section describes the metadata.

7.6.1.1. Satellite image processing

The Indian Remote Sensing satellite was used to classify and create the forest land cover map. The major reason for the use of satellite image is to study the temporal changes and to provide a rapid update of the forest land cover in the study area (user requirement 4: chapter 6). The following section demonstrates the description of the image, the different tools used, and the methodology followed, for processing the image.

The detailed processing steps are shown in Figure 7.5. Firstly, the image was geometrically corrected with ground control taken from topographic maps and the study area was extracted by digitising the range and village boundaries from Forest survey maps and masking them from the areas outside Banavasi Range. Using knowledge gathered from the field with the False Colour Composite (FCC), training areas were selected for all the possible categories. These areas were used to train in both Maximum Likelihood Classifier and Artificial Neural Network (ANN). The reason for the use of the ANN classifier is to check whether this classifier helps in increasing the classification accuracy, which is discussed in the next paragraphs.

In classifier ANN, three channels such as 1, 2 and 3 of IRS data were fed as input, with 9 hidden layers and 9 outputs (Figure 7.6). The classification was performed using the image processing software EASI/PACE (PCI) & ERDAS IMAGINE, and finally, evaluation of the accuracy was carried out on the processed image, with the help of a set of field survey data and existing forest survey maps (1: 14,800) and ground truth survey. The classified output of IRS data using both ML and ANN classifiers is shown in the Figure 7.7 and Table 7.3 reports the comparison of classified pixels in both classifiers.

The ANN based classifier produced a better overall performance than the ML in classifying the forest land cover using the IRS-1C (LISS-III) satellite image (Sugumaran et al., 1998). The ANN classifier showed higher accuracy for two classes water and *forest plantation*. However there was no significant difference in classifying the area of the homogenous natural forest. Finally the ANN based classified image using the neural net classifier was stored in a raster format.

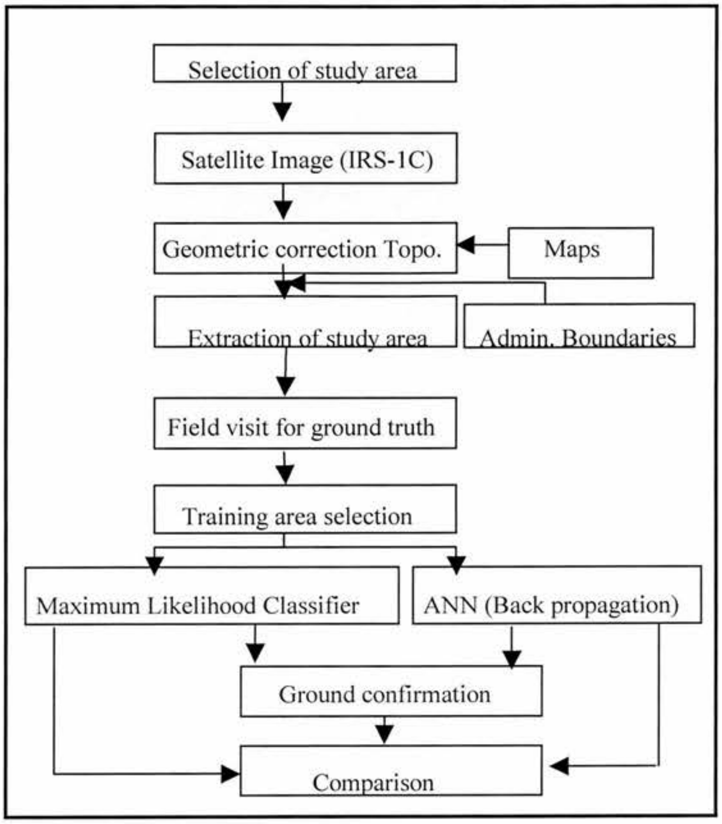


Figure 7.5 Schematic diagram of the methodology used in image Processing.

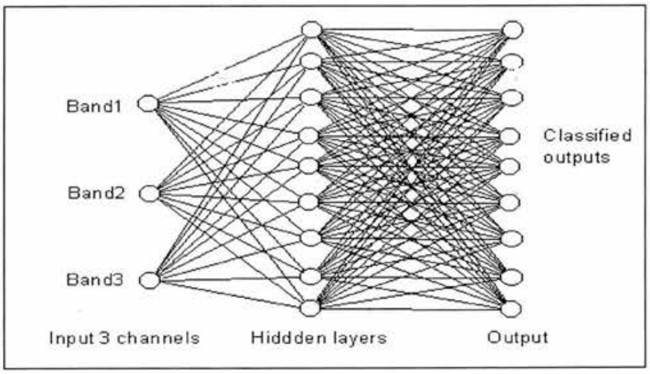


Figure 7.6 the basic structure of an ANN used for the IRS image

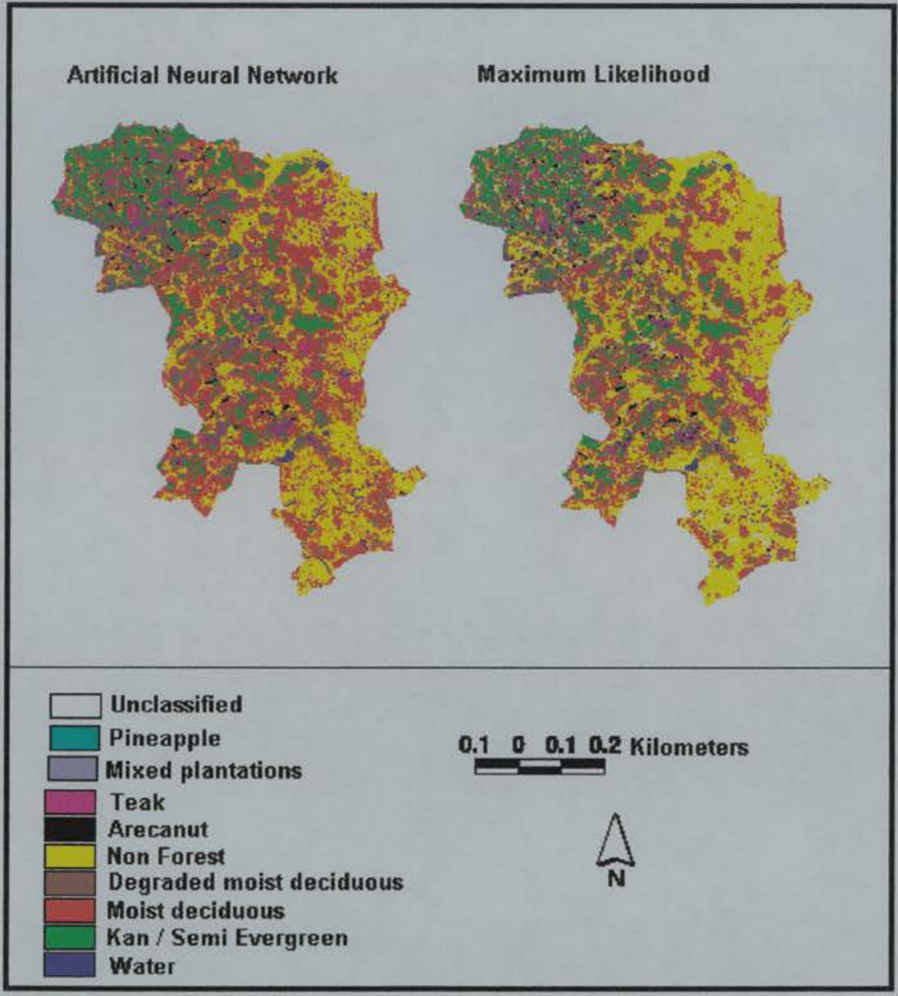


Figure 7.7 Comparison of supervised and ANN outputs

Table 7.4. Classified output (by pixel) for ANN and ML.

Category	ML Pixels	% area	ANN Pixels	% area
Unclassified	17167	3.4	1	0.0
Mixed plantations	60752	12.0	51213	10.1
Teak	27501	5.4	35154	6.9
Arecanut	4396	0.9	3288	0.6
Pine apple	7343	1.5	29814	5.9
Non – Forest	208387	41.2	150663	29.8
Moist Deciduous Forest	69601	13.8	71158	14.1
Degraded MDF	88640	17.5	140941	27.9
Kan / Semi evergreen	19625	3.9	19114	3.8
Water	2645	0.5	4711	0.9
Total	506057	100.0	506057	100.0

7.6.1.2. Conversion of existing maps

The collected data from all the spatially related maps such as soil, geomorphology, forest land use, administrative boundaries, and forest survey maps were digitised from the hard copy to digital vector format. ARC/INFO GIS software, which is the most widely utilised GIS software was chosen for use of data capture and conversion. All the maps were initially digitised and imported to Arc/Info software. Then, all the coverage's were edited and projected to a poly-conic projection (This projection is suitable for India because it is true to scale along the central meridian and along each parallel). Finally all the information were added in the INFO database and stored in the workspace as vector format. Administrative boundaries (Figure 7.8), roads (Figure 7.9), canals (Figure 7.10), and Forest survey map (Figure 7.11) are some of the initial digital output produced from the software.

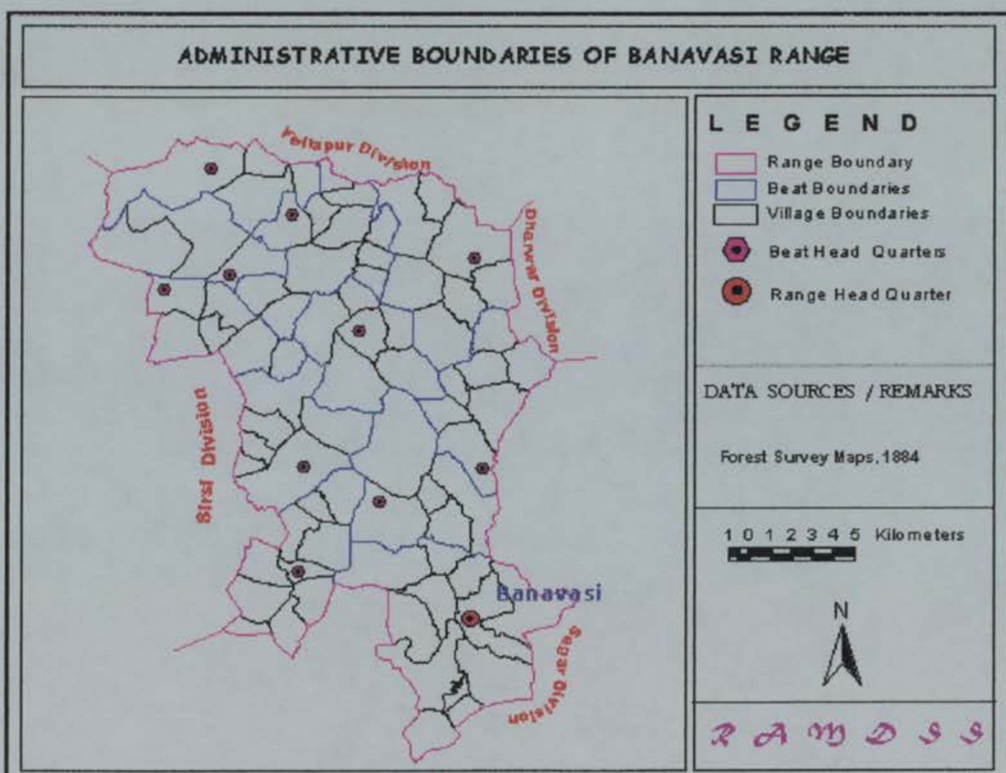


Figure 7.8. Administrative boundaries in the study area

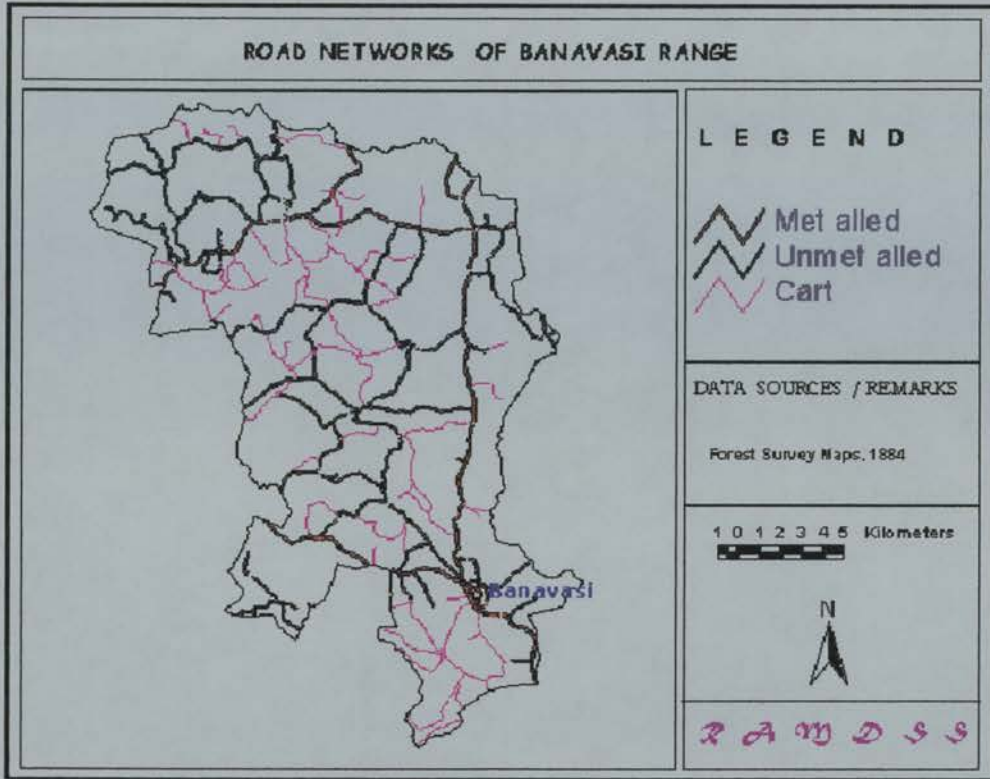


Figure 7.9 Road map of Banavasi range

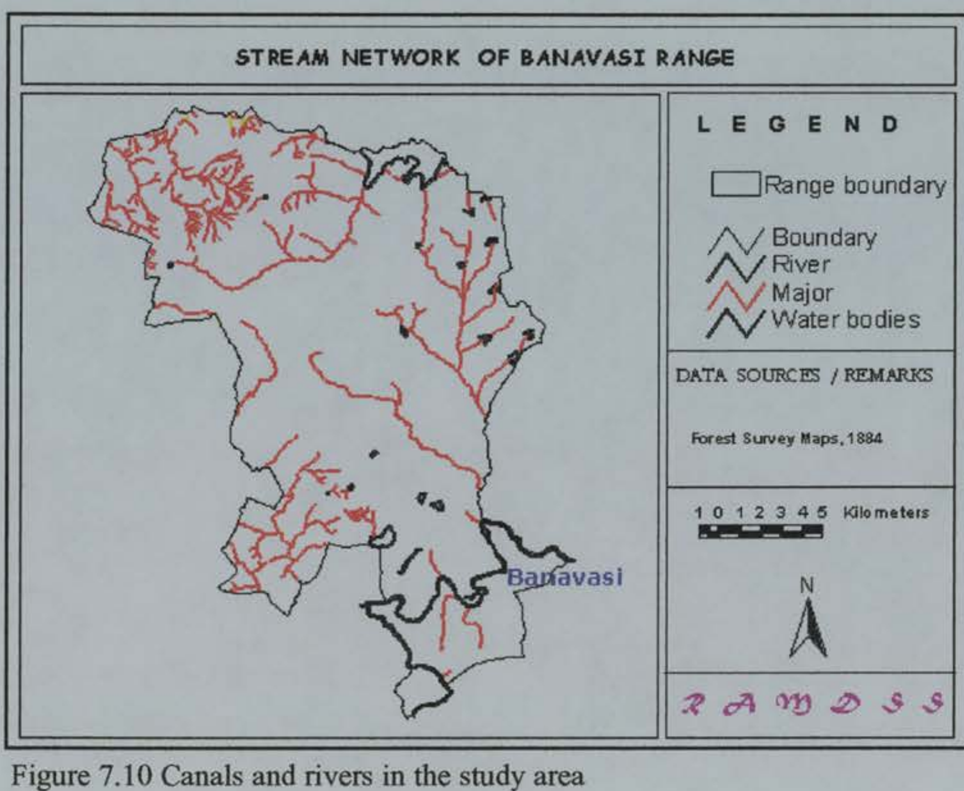


Figure 7.10 Canals and rivers in the study area

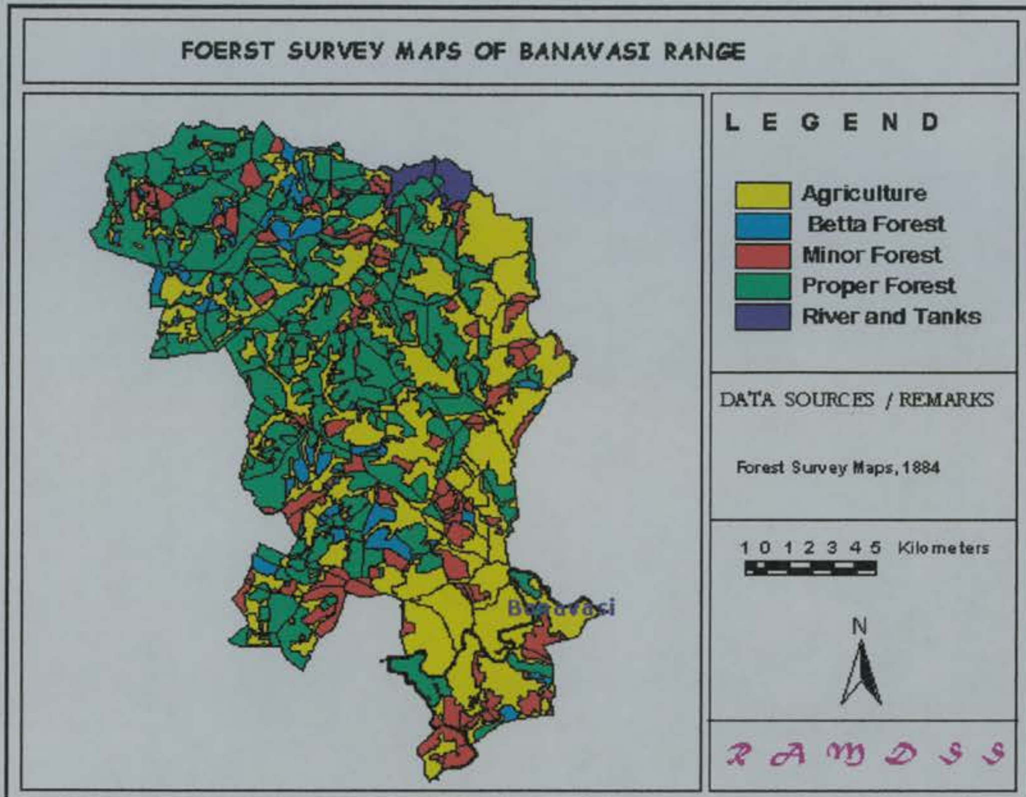


Figure 7.11 Forest survey map of the Banavasi Range

7.6.1.3. Metadata for spatial data.

The metadata file is information about the data. The description of each unit of the spatial data is described in the database as text files. The description includes: Identification Information, Data Quality Information, Spatial Data Organisation Information, Spatial Reference Information, Entity and Attribute Information, Distribution Information and Metadata Reference Information. This metadata was created using the Minnesota Geographic Metadata Guidelines. Table 7.5 shows the model metadata created for the forest land cover map produced using Indian Remote Sensing Satellite data. The main purpose of generating the metadata is to provide information on data standards, and data quality, for other users who need to determine whether the data meet a particular need and to be able to judge the fitness for use.

Table 7.5 Metadata description for the land cover data

METADATA for Indian Satellite remote sensing image based Land Cover map (Raster).

1. Identification Information

Originator: National Remote Sensing Agency

Title: IRS-Based Land Cover map (Raster)

Abstract : Raster-based land cover data set derived from 23 meter resolution of the LISS–III Sensor. Classification is divided into 9 classes with source imagery date Feb. 1997.

Purpose : Land use planning, natural resource monitoring

Reference Date of source imagery (IRS–LISS–III, Bands 2, 3 and 4) of Feb 16th 1997. The path/row number and image are 35 and 104.

Spatial Extent of Data:

An area covering the Banvasi Range region of Sirsi Divisioin, of the western Ghats, India.

2. Data Quality Information

Attribute Accuracy:

The data set exhibits a per class and overall classification accuracy of not less than 85 percent. The accuracy of the processed image, a set of field survey data and existing forest survey maps (1: 14,800) were used as the ground truth necessary for the assessment.

Logical Consistency: Data are stored within a valid ERDAS Imagine data structure.

Completeness : Data provides complete coverage over the stated extent of the data

Horizontal Positional Accuracy: Unknown.

Vertical Positional Accuracy : Not Applicable

3. Spatial Data Organization Information:

Native Data Set Environment : ERDAS Imagine

Spatial Object Type : Raster

classes: Nine forest cover classes

1.Arecanut
2.Mixed plantations
3.Teak
4.Pine apple
5.Non – Forest
6.Moist Deciduous Forest (MDF)
7.Degraded MDF
8.Kan / Semi evergreen
9.Water

4. Distribution Information

Publisher
Karnataka Forest Department
Publication Date

12/09/1997

Contact Person Information

Dr.Swaminath
Director
Karnataka Forest Department
Vanavikas
Banglaore, India.

5. Metadata Reference Information

Metadata Date : 02/03/1998

Contact Person :

R.Sugumaran
Department of Geography,
Drummond Street,
Edinburgh UK.

Metadata Standard Name:

Minnesota Geographic Metadata Guidelines and

Developed by R.Sugumaran

7.6.2. Non-spatial data conversion

One of the important data requirements in the project is to collect non-spatial data for the effective forest planning (See Chapter 5). The collection of non-spatial data in this project mainly through by questionnaire survey and forest vegetation data collected through transect studies (user requirement 4, Chapter 5). The collected secondary data such as socio-economic and forest inventory information were stored in the database. The detailed data collection is given in the Appendix 3. The information collected from transect studies were modified and used in the vegetation analysis using PC-ORD package. The main goal of this study is to analyse the forest vegetation using ordination methods (user requirement 4). Ordination is a method, which attempts to reveal the relationships between ecological communities. The analysis mainly includes multivariate statistical analysis using different software such as DECORANA (Detrended Correspondence Analysis), TWINSPAN (Two Way Indicator Species Analysis), and CANOCO (Canonical Correspondence Analysis). These data served as input for modelling and satellite image processing.

7.6.3. Elicitation of Knowledge

The detailed method for the construction of the Knowledge Base is given in Figure 7.121. The information was collected though extensive interviews with experienced foresters, and from local people. In addition, information was also consulted from existing reports and records, published books and floras (Figure 7.12). The acquisition of knowledge and its effective transfer to a meaningful database is complex and involves a diversity of activities (Hayes-Roth, 1993). One of the examples developed in this study is to assist the non-botanist, in the identification of medicinal plants from the vegetative characteristics such as leaf venation, arrangement, shape and margin.

The collected information was stored as *facts* and *rules* in the knowledge base. This was achieved using logic programming (Prolog). Facts describe fixed properties of knowledge, while rules are used to deduct new facts from the existing facts

(Skidmore et al., 1996). For example, describing the plant *Sida rhombifolia L.* involves:-

species *Sida rhombifolia L.* is a dicotyledons .... fact;

If species has leaf venation reticulate and
leaf arrangement alternate and
leaf shape obviate and leaf margin serrate then
it might be a speices *Sida rhombifolia L* .... *rules*

The main aim of this approach is to help the inexperienced planners to consult the system and to assist in making better decisions. In order to facilitate user interaction, a user interface was developed within the system. Figure 7.12 explains the whole process involved in the development of knowledge base for the medicinal plants.

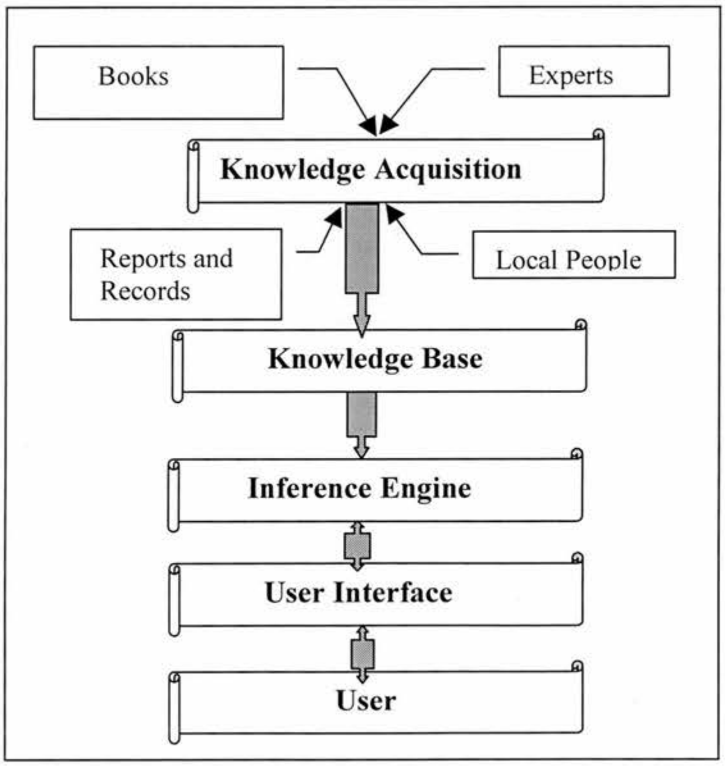


Figure 7.12 Development process for the knowledge base

7.7. Summary

This chapter has examined the nature of the different data collected in order to develop the prototype. The data collection was grouped into three categories based on the nature of the data. The categories are spatial, non-spatial and knowledge base. The spatial data include existing maps such as forest land use, soil and geology. In order to update the land cover map, recent satellite images were used and the image was classified using ERDAS IMAGINE software. Metadata were also created for all the thematic maps to show the data quality and data standard. The non-spatial data covers socio-economic data, forest inventory data and other statistics from the forest department. The knowledge base was collected from the experts from the field, published books, reports and records from the KFD. Finally all the data were processed using different software and stored in the relevant database for future analysis. The last three chapters have explained the user requirements, conceptual design and implementation, and data collection and processing for the development of the prototype RAMDSS. The next chapter demonstrates how RAMDSS can assist the Forest planner in the study area, with an illustrative application.

Chapter 8: Application Example using RAMDSS

The purpose of this chapter is to demonstrate how the prototype RAMDSS can assist planners (specifically forest Rangers) to take effective decisions in the study area. In order to explain the steps involved in the decision-making process, the description of the functionality of the system is divided into different sub-sections based on the user requirements. The first section explains how to set up the database (which includes collection, editing, query and visualisation) before running the models. The second section summarises and justifies the different models available in the system and shows how they can be used in the planning process. The final section demonstrates how the result output, in the form of maps and reports can be generated within RAMDSS.

8.1. Overview of the top-level user interface

The functionality of the RAMDSS is accessed through pull-down menus, buttons, and click tools which were discussed in detail in chapter 6. Figure 8.1 illustrates the main screen layout of the RAMDSS interface. The decision supporting process involves three main phases - the ***Data Manager***, ***Model Manager*** (commands are shown as bold Italics), which includes ***Production Manager*** and ***Protection Manager***, and finally, ***Display Manager***.

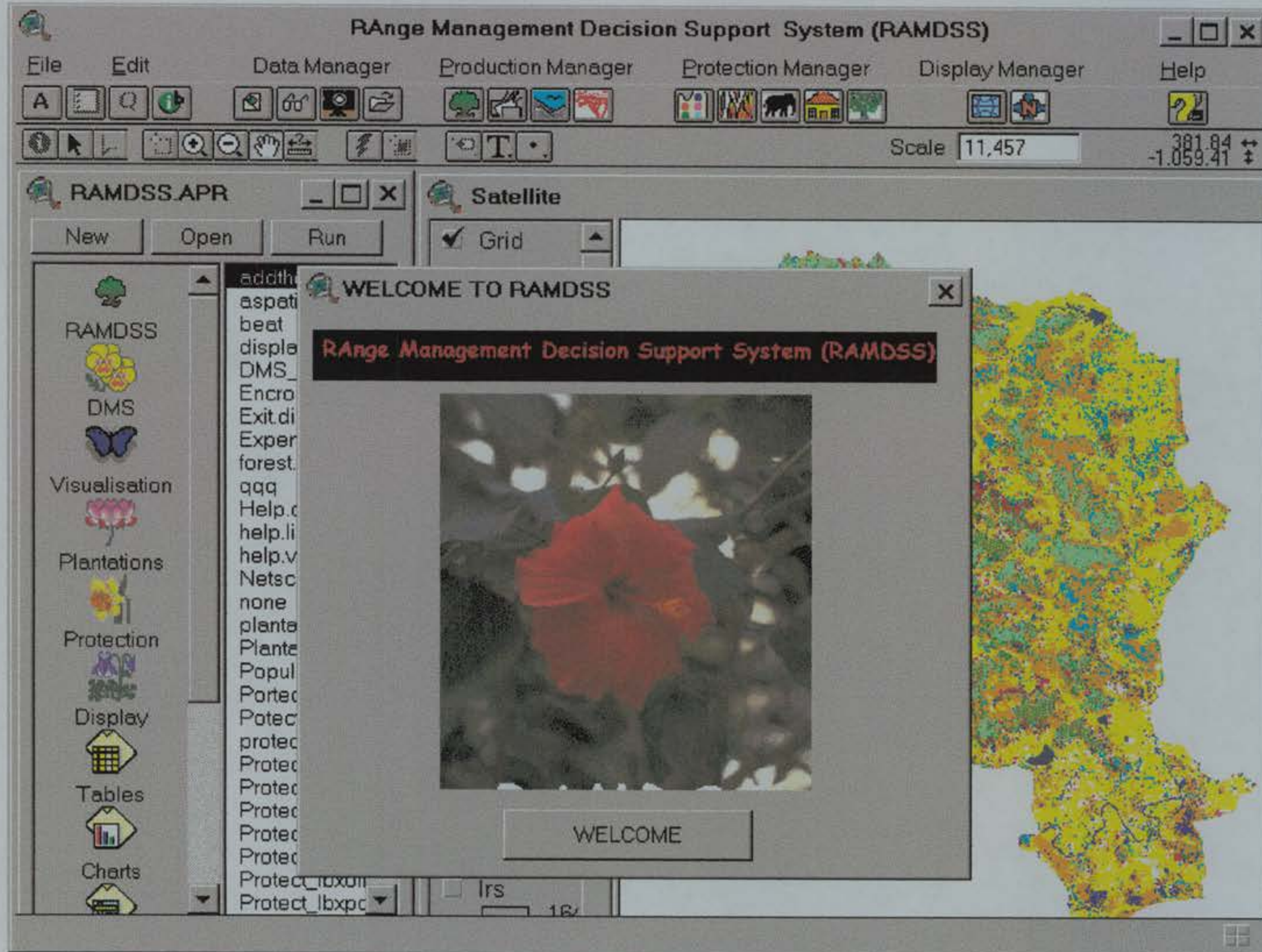


Figure 8.1 Main interface window of the prototype RAMDSS

(Chapter 6). In the first module, managers collect and maintain the relevant data. In this phase, with the help of collected information, a potential user can run the required model and view the results. In the final phase the results from the model can be produced as a map layout or report. The detail steps involved in each module are discussed in the following sections.

8.2. Introduction to application example

As mentioned earlier, the main aim of the system is to assist the decision-maker (Forest Ranger) in the day to day planning process. In order to assist, different models were created based on the user requirement, for example, a plantation model, a model dealing with the protection of endangered or medicinally important species, a fire protection model. The following example explains in detail how the protection of a *Medicinal Plants model* can help the planners to take effective decisions using the RAMDSS. The next paragraph gives a brief introduction to the importance of the medicinal plants in the study area and why they need to be protected.

8.2.1. Description of the medicinal plants protection model

One of the important problems faced by Ranger in the Banavasi Range is the need to conserve medicinal plants. The Banavasi Range represents one of the most important areas for medicinal plants in the Western Ghats (KFD report, 1995). Recently the human population explosion, coupled with improved standards of living, has led to un-managed exploitation of these plants, resulting in the imminent danger of extinction for some of them. This large-scale destructive collection from this area has resulted in pressure for greater conservation and sustainable use. A recent Conference (Medicinal Plants Conservation, Utilisation, Trade and Intellectual and Cultural Property Rights, Bangalore, India) organized by the Foundation for Revitalization of Local Health Traditions (FLRHT, 1998) thoroughly discussed the problem of degradation and emphasized the need for conservation in this area. In addition, several government and non-governmental organizations have already been warned of the problems (Kushalappa, 1995; Brooks, 1996; FRLHT, 1998).

Conservation of these plants requires detailed information on a range of topics from environmental to specific use particularly concerning the local name, medicinal value and location (Sugumaran et al., 1999b). The requirement for planning includes, amongst other issues, the collection of plants, identification of plants, and finding the suitable areas to protect these plants.

In order to achieve these goals, a *Medicinal plants protection model* was incorporated in the RAMDSS. The aim of this model is to assist forest planners in the decision-making process on how to protect the medicinal plants in the study area. The protection of these medicinally important plants may require different decisions such as:

1. How to identify the medicinally important plants (e.g. local name, botanical name, medicinal value etc.), if the planner is not is experienced taxonomist;
2. How to collect and how to add rare or endangered species into the plant data base in order to update;
3. The planner may want to visualise the plant and explore the plants descriptions to understand the detail of particular plants;
4. The location of the plants (for example, relevant to a newly posted Ranger Forest Officer)
5. Suitable areas for the conservation of these medicinally important plants? (for both novice and experienced planner).

The next section explains how to solve these issues using the medicinal plant protection model with RAMDSS. The next paragraph explains how to identify the plants through a query system.

8.2.2. Identification of the medicinal plants

As mentioned earlier, the conservation of medicinal plants required the details of the plants such as location of plants, identification of plant name, medicinal value of the plants. Identification of these plants without an experienced taxonomist is very difficult and planners have to depend all the time on the taxonomist for identification, because of very rich plant diversity in this area (See chapter 4). The present system allows the planner to identify the plants using the ***Query*** command in the ***Data Manager*** (Figure 8.2).

Figure 8.2 Data Manger module in RAMDSS

The major function of this command (***Query***) is to assist the user to explore the existing data sets, ask simple queries, and to view the results as a text or graphs or images or video clips. The Q***uery*** command uses a hierarchy for the identification and location of the plants (Figure 8.3). The user will then be allowed to select his/her interest by clicking the appropriate window or button to reach a particular method. As an illustration, the procedure is followed through an example.

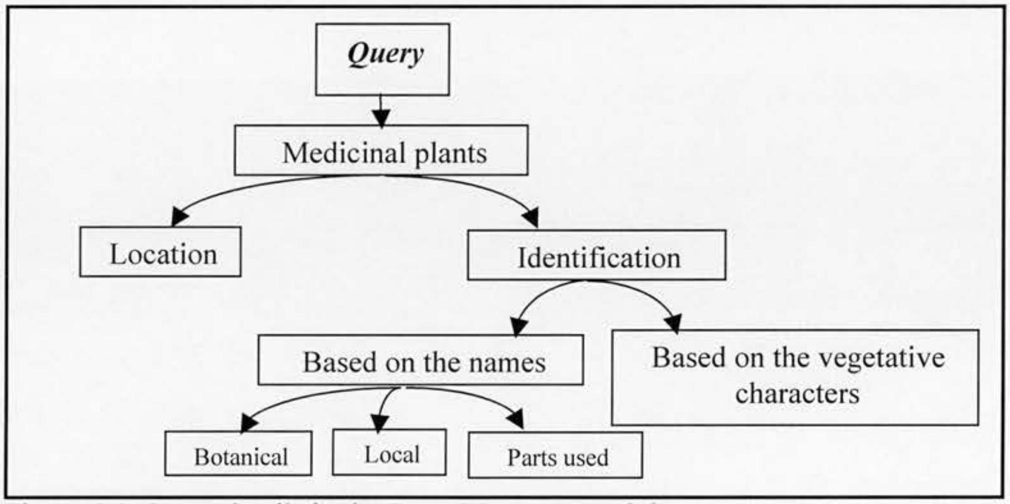


Figure 8.3 ***Query*** details in the ***Data Manager*** module

Aim: Imagine that the planner has to conserve a particular plant (for example: Sarpagandhi) because it has highly medicinal value for heart diseases; it therefore also has a high commercial demand and is being reduced at an alarming rate. Let us assume the planner knows only the local name of the plant (not being an experienced taxonomist) and nothing else. In order to conserve this plant he has take several decisions involving, finding out plant details such as the botanical name, family name, which parts are used for a medicinal purpose, how to identify the plants, where they are located in the study area, how to conserve them? etc. The next paragraph explains how these issues are resolved in RAMDSS.

The first method to help the planner to identify the botanical name, family name, habit, parts used, and to the remedy for which disease (etc) is based on the local name. In order to find out these characteristics the user can select the *local plant identifier* window and select a particular plant (Sarpagandhi) from the list within the pop-up window and click the OK button (Figure 8.4). The selection of local name Sarpagandhi generates a report pop-up window showing all the details - botanical name (*Rawolfia serpentiana*), family (Apocynaceae), parts used for medicinal value (roots), and remedy for which ailment (heart diseases).

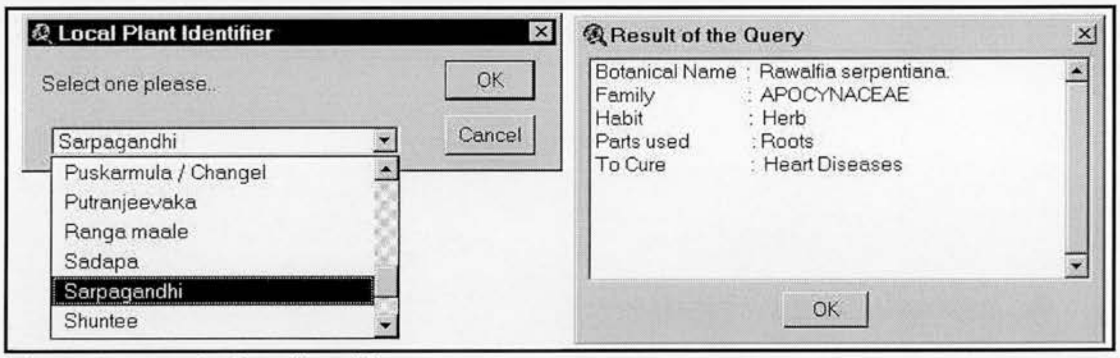


Figure 8.4 Local plant identifier

Vice versa, the user can also use diseases or a symptom identifier, or a plant parts identifier (etc.) to find out the other details. Now, the planner has identified the names and descriptions of particular plants such as botanical name, family name, habit, parts used, and to remedy for what disease (etc.). The next question considers how to identify the plants without taxonomic assistance in the field. The Knowledge Based System module helps the planner to identify the plants based on only the vegetative characters. The knowledge was developed after interviewing an experienced taxonomist and referring to various floras and books and stored as a knowledge base in the Sicstus Prolog. The reason for use of the knowledge based system is that it is easy to edit the knowledge base, for example by adding a new character into the knowledge without changing the code. This example also demonstrates how ArcView and Sicstus Prolog are linked. Figure 8.5 demonstrates the interface developed using dialogue designer for linking ArcView and the Knowledge based module.

From the experienced taxonomic database, the vegetative characters such as leaf venation, leaf arrangement, leaf shape, leaf margin and leaf types can be used for the identification plants in the study area. By comparison with the sample plant, the user answers a series of questions, and the resulting identified plant will be shown in the interface (Figure 8.5). The Knowledge Based System for identification of medicinal plants is designed to represent and reason with "knowledge" concerning the vegetative characteristics of medicinal plants by answering a series of optional questions. There are four predicates (characters used to reason) namely Char, Char_type, Char_list, and Species. The main predicate species was used with two arguments namely Species_name and Char_list. The example for the representation is given below

species(Species_name,Char_list).

Example:

species(*Rawolfia*,[ret,alt,ova,ent]).
which can be read as,

There is a plant species *Rawolfia* which has the following plant leaf characteristics: reticulate venation, alternate arrangement, shape ovate and margin is entire.

The predicates are simple, easy to understand by a Forest Ranger and easy to update. Although the present method used only few predicates, more predicates may be added at a later date (and the inference engine modified to cope with them) if any knowledge arises that is crucial for species identification but un-representable within the present scheme. In other words, it is a flexible and open system and can be modified according to need.

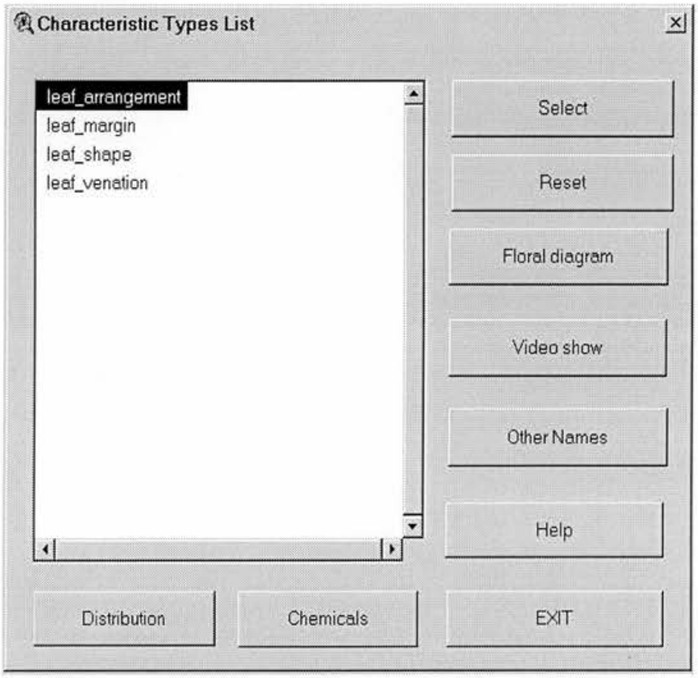


Figure 8.5 an Interface developed to link ArcView with Sicstus Prolog

The inference engine, once triggered to run by the interface using a select button from the interface in ArcView (Figure 8.5), then goes to Sicstus Prolog, and construct the knowledge base and brings the result as a display on the interface, based on the character types for which the current knowledge-base has information (Figure 8.5). It will then prompt the user to select the type of character (e.g. leaf venation or leaf shape etc.) that they wish to examine from the list of available character types. Based upon the selection, the inference engine will then construct and display a menu of the plant characters belonging to that type from the current knowledge-base transfer to the interface. Here the data is between the two packages. It will then prompt the user for input concerning the character that they of interested in (probably a characteristics of the species they wish to identify). Over the whole process, the user never realises that he/she is using two software packages.

Based upon the user's character input, the inference engine will construct a list of all species represented in the knowledge-base with the predicate 'species'. It will then search this list extracting and displaying all species (if any) which have the character of interest to the user. The results list produced may contain zero, one or many species. Then the user is also given the opportunity to view the video coverage, floral diagram, chemical constituents, distribution, and local name of the selected plants (Figure 8.5).

8.2.3. Location of the plants

The third question relates to where this plant is predominantly occurring in the study area. It involves identification of location using GIS. In order to find out the location the user can use the location identifier which brings an in-built ***query builder*** available in the software (Figure 8.6). The user can set the criteria and then view the relevant location on the map (Figure 8.7). The stars in the map (Figure 8.7) shows the location of the particular plant based on the information collected from the transect study.

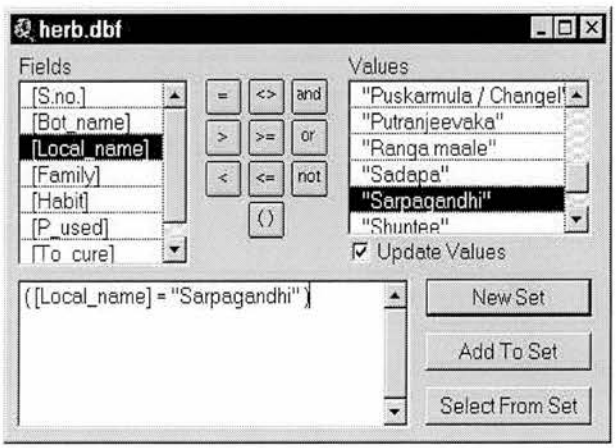


Figure8.6. Screen shot of the ***Query builder***

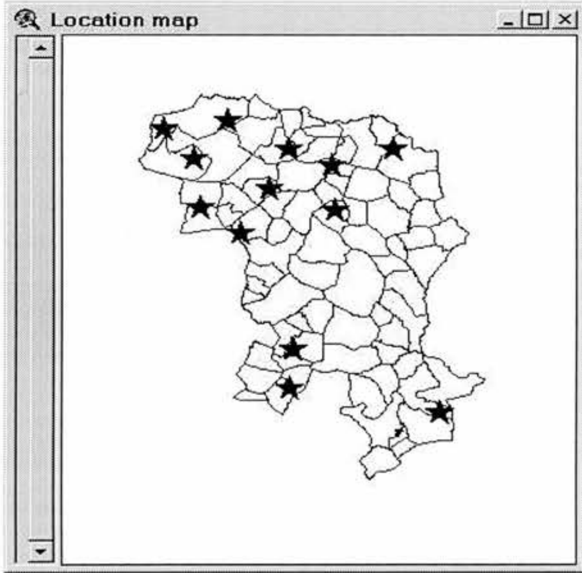


Figure 8.7 Query result for the ***query builder***

After successful identification and location of the plant, the user is also given the opportunity to view the plants by different methods such as an image, video clips, 3-D animation etc. The visualising of these different methods is given in more detail in the next section.

8.2.4. Visualising the plants:

As mentioned in chapter 3, visualisation is a form of communication which is universal, and which has the ability to form an abstraction of the real world into a graphical representation. In order to achieve this in the present study, a scanned image (supported by gif, or jpeg or tiff formats), the video files and 3-d animation (avi format) were produced. For example, in order to see the location of the plants, the user may also interact to chose a specified sample plot and see the available plants lying within it.

The main aim of visualisation is to aid the planners, particularly newly posted Rangers to understand the different facilities available within his/her areas of interest. In addition, it allows the planner to retrieve and display the existing data sets available in the RAMDSS. For visualisation of the data, the user may go to the***Data***

Manager menu on the menu bar in the main window and the select the command ***Visualisation*** (Figure 8.2). Let us continue with the example taken in the last section i.e. medicinal plants. Now the planner is interested to understand more about this plant such as a live demonstration of the plant, botanical description such as floral diagram, anatomical structures etc. of the identified medicinal plant *Rawolfia serpantiana*. There are three options given within RAMDSS to fulfil these requirements and they are: scanned images, video clips and 3-D animation. The first example shows the 3-d animation through a "fly-through" method to view the overall study area (Figure 8.8).

If the user wants to see the entire plant with flowers, leaves etc. (live demo.) then he/she can use the video option (Figure 8.9). If the user is interested in the botanical characteristics then the third option fulfils the request through the images. This option is shown in the Figure 8.10.

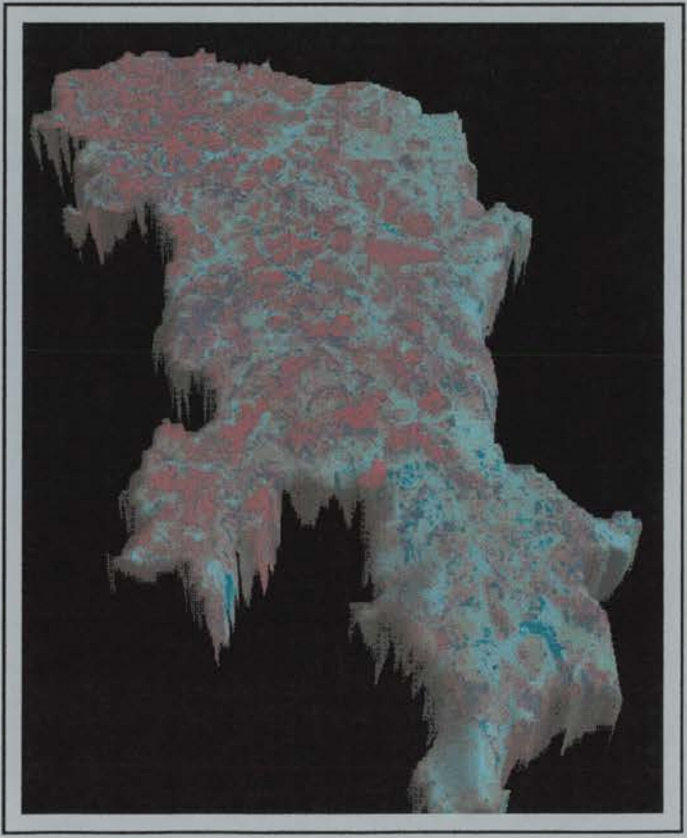


Figure 8.8 Example for 3-D animation through Fly-through model

Figure 8.9 Video clips example of the plant

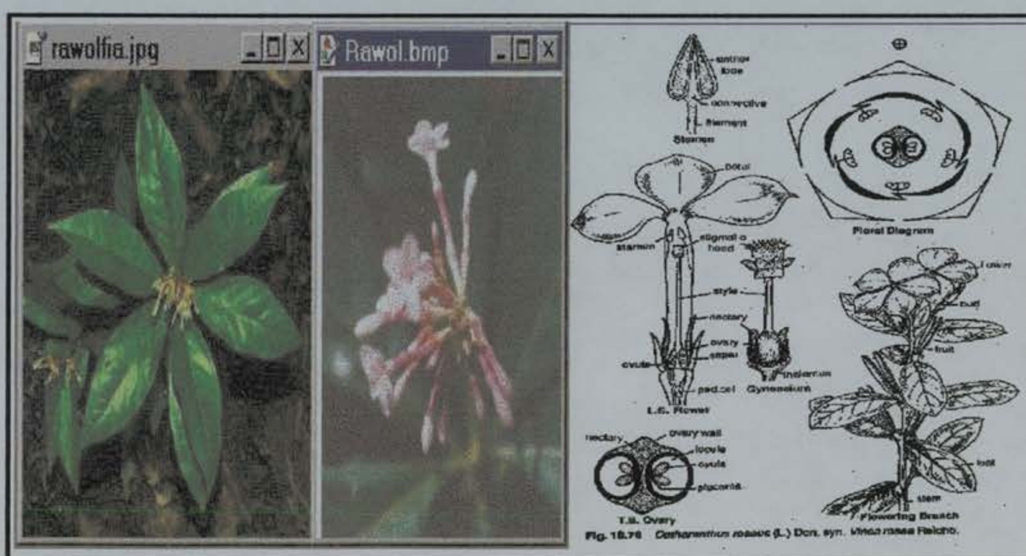


Figure 8.10. Example for images

8.2.5. Adding new data to the data base

This option allows the user to add new spatial or non-spatial data from the different sources into the system. In order to add new data, the user may go to the ***Data Manager*** module and then select a command ***Data collection*** (Figure 8.2). Adding new spatial data includes different formats supported by ArcView software. The spatial format supported by the system includes ArcView shape file, ArcInfo, Autocad, and Intergraph, Mapinfo and ASCII format, whereas the non-spatial data supported formats include Info, delimited text, mdb of MS-Access and dbf. After identification of plants, locating the plants, and viewing the plants, the user may want to add some new information about the particular plant, say for example, a new data set called "commercial value" of medicinal plants as a new field in the table. This can be done by the ***Data collection*** command, which allows the user to create a new table to edit the existing table through a simple interface.

8.2.6. Maintaining the existing the database

The data maintenance function allows the planner an easy way to modify or update spatial and non-spatial databases. Once the user selects the ***Data maintenance*** function from the ***Data Manager*** module, it allows his/her to choose either on spatial or non-spatial data sets for editing purpose. Figure 8.11 is an example showing the selection of a soil map (spatial data). For example, the user wants to add more sample points in the spatial data: this can be easily selected as a suitable theme and edited. The same way user can also select the suitable tables and update or edit them. Figure 8.12 explains the editing of existing table, which was created using MS-Access forms. The main reason for this option is to provide easy interface and a facility for updating the database.

After identifying the plant name, location, adding new data, and editing the existing database the user may want to find out the appropriate areas for protection or conservation in the study area. The next section explains this problem with a modelling approach.

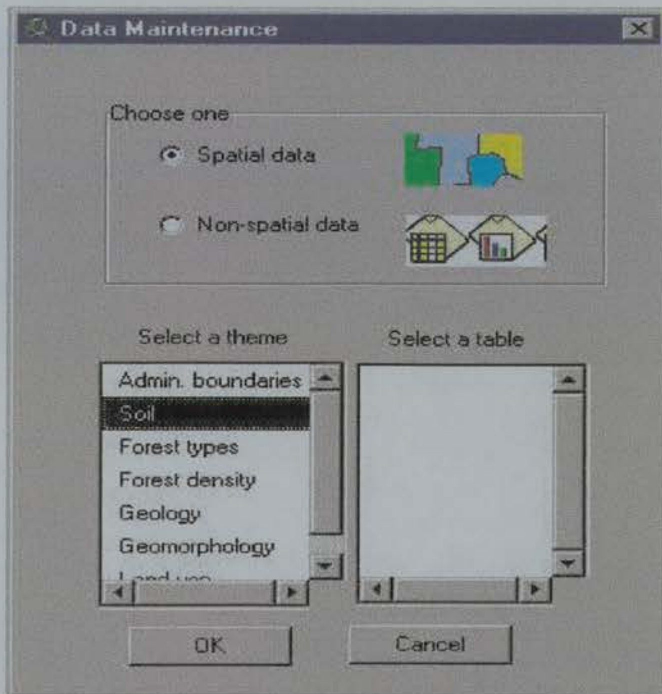


Figure 8.11 Pop-up window for the data maintenance

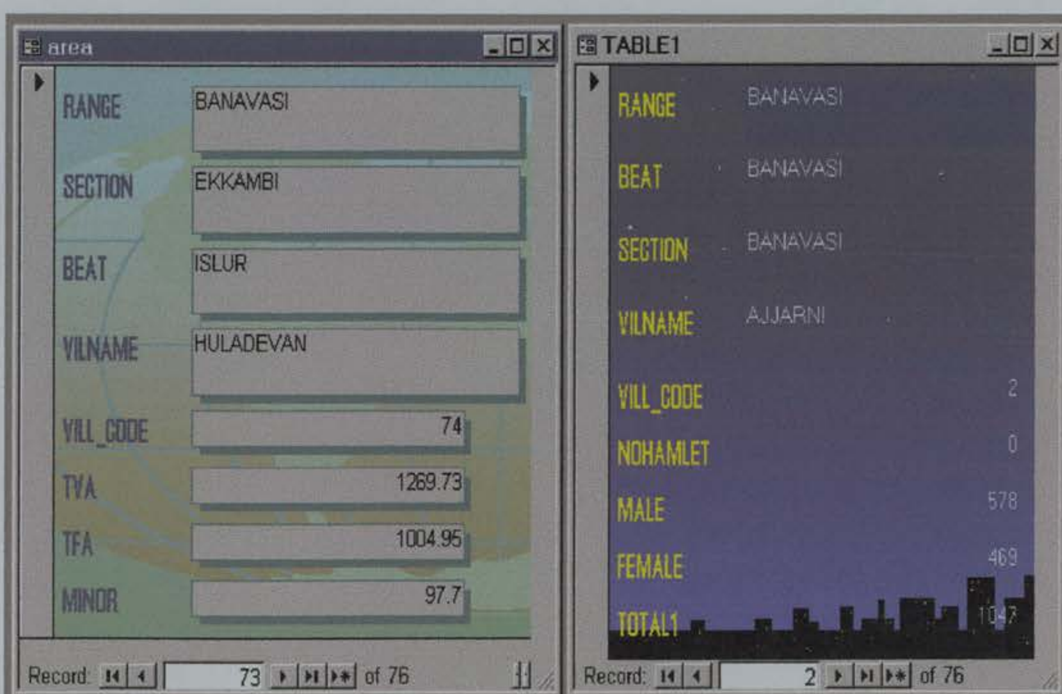


Figure 8.12 Table input forms produced using MS-Access

8.2.7. Locating suitable areas for protection (through a modelling approach)

The manager is interested in finding out the suitable areas for protection after learning about the names, description of plants and the uses of such plants. This can be achieved through a medicinal plant model provided within the RAMDSS. For this model, the user may go to the ***Protection model*** menu on the menu bar in the main window and select the command ***Medicinal plants*** (Figure 8.13).

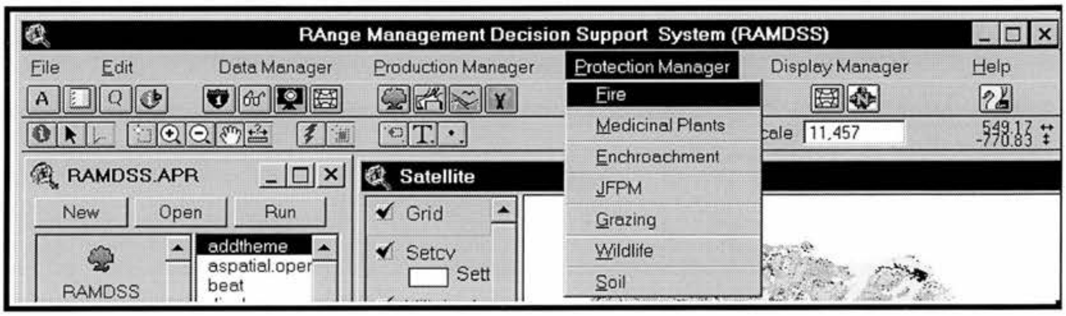


Figure 8.13 protection Manager in the main window

All the models in the RAMDSS follow the same sequence of steps. This sequence of steps in the planning cycle is illustrated below (Detail shown in Figure 8.14):

Step 1. Setting up the database;

Step 2. Selecting a required model;

Step 3. User level choice (Experienced or inexperienced);

Step 4. Evaluating the alternatives; and

Step 5. Output of the results from the model.

In the following paragraphs, each step of the modelling process is explained in detail. Although each model has different set-up criteria, the process will be explained with this example, how to run a medicinal plants protection model.

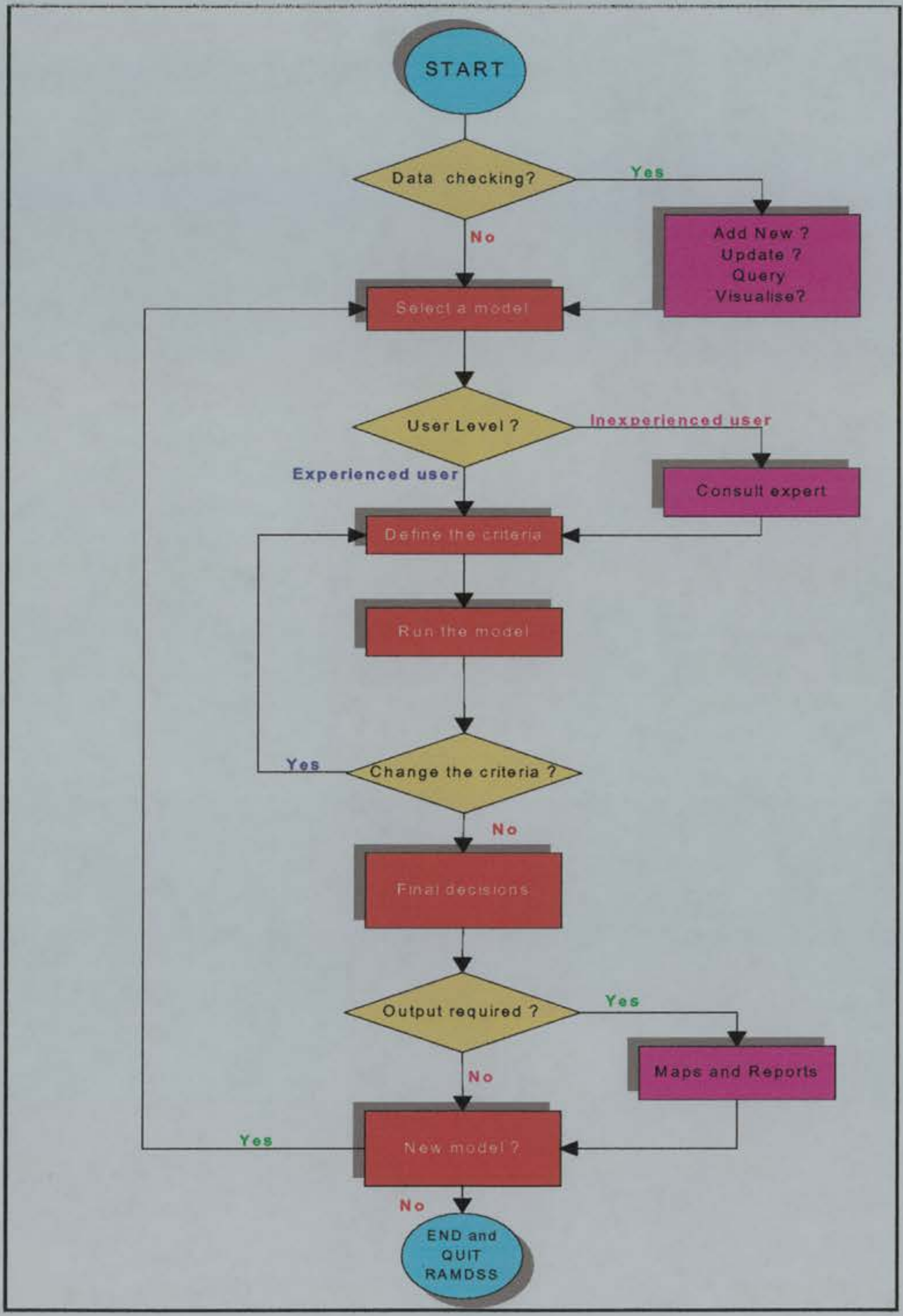


Figure 8.14 Example of model flow in RAMDSS

Step 1: Setting up the database

An analysis begins with the selection of the required model (in this example: medicinal plants protection) either from menu bar or from a button on the tool bar (Figure 8.13). Step 1 is the preparatory stage before running a model. It allows the manager to add new data into the database, update the existing data, query the existing data sets and visualise the existing data sets. All these functions are available in the ***Data Manager*** module and discussed in the last section. If the manager does not want to modify or update the database then he/she can straightaway run the required model.

Step 2: Selecting a required model

The value of any DSS lies in the assistance it offers to the planners to examine different alternative strategies for a particular problem (Fedra, 1995). In order to achieve this aim, in RAMDSS, the ***Model Manager*** module (which includes both production and protection models) was developed (Figure 8.1). The major purpose is to help the managers with a simple graphical interface, which enables the user to manipulate the database, run the required model, and view the results in an interactive session. There are several static models included in RMADSS, the design of which is based on the user requirements.

In order to develop suitable models, experts in the study area were interviewed and the following models resulted from these interviews. Based on the information collected, ***Model Manager*** was grouped into two major sub-modules, namely *production* (mainly dead and fallen timber collection, Non Forest Timber Produces (NFTPs), and tourism, *protection* (which involves models such as fire, soil, encroachment, illegal cutting, grazing, and wildlife and plantations).

Ideally the decision-making process requires the identification of the objectives, the development of alternative actions and comparison of the likely results of such actions with the original objectives, finally choosing an alternative for the implementation (Chapter 3, Figure 3.1). The following sections describe how these sequences are developed in the RAMDSS by selecting a *Medicinal Plants Protection Model (MPPM)* for the conservation menu.

Step 3: User level choice

Although decision-makers are knowledgeable, for the most part they are not experts in methods of spatial and decision analysis. Keeping the problem of providing a service for both the experienced and inexperienced user in mind, the user level was divided into two groups. One pathway was to provide assistance to less experienced user and this is dealt with by incorporating expert opinion in order to solve a particular problem. This was achieved through coupling a Knowledge based module with the RAMDSS (Figure 8.15).

An experienced user can straight away set the criteria based on the experience they have; then run the model, view the alternatives, and finally take appropriate decisions (Figure 8.14). Whereas the less experienced user (e.g. a recently appointed Range officer) may require some assistance in understanding the model. In order to get assistance the less experienced user can go to the KBS module and then ask different questions about the particular model, for example, what can the model offer? How does it work? What are the parameters required? Once the user has understood the problem, he/she can exit from the KBS module and return to the modelling module, to set the criteria and run the analysis (Figure 8.15). Figure 8.15 is the user interface developed for the Medicinal protection model using Sicstus Prolog. For example users can click the *experts view* button in the model interface and then it takes the user to KBS module where he/ she can explore the detail through interactive learning about the model and return to the model interface by typing "halt" (Figure 8.15).

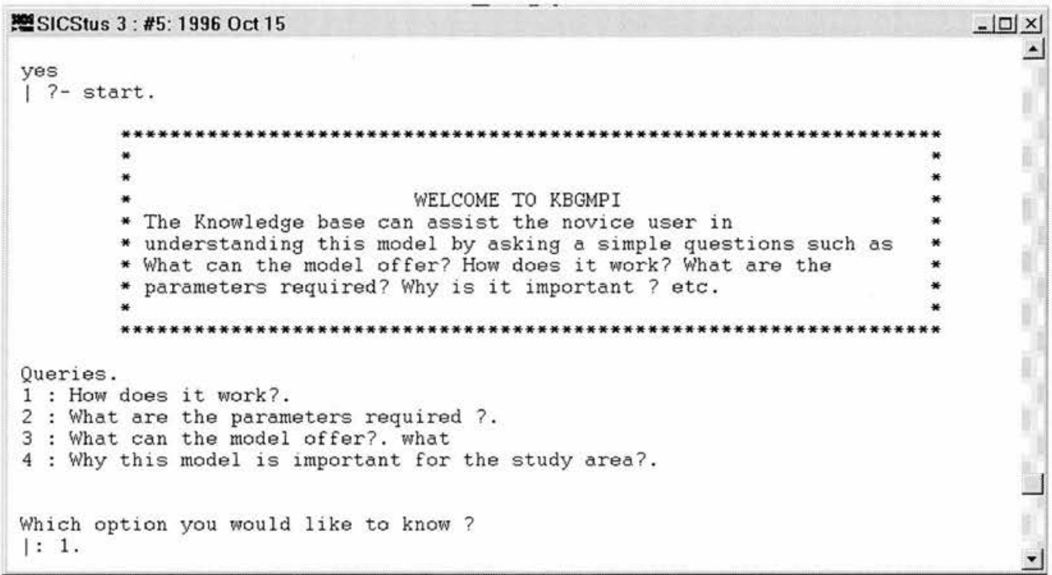


Figure 8.15 Stand-alone system developed using Sicstus prolog

Step 4. Evaluating the alternatives

The main aim of this step is to provide the opportunity to evaluate the different options available within the *medicinal plant protection model* and view the results (Figure 8.16). This model is designed to assist the manager to locate the areas requiring a protection for particular medicinal plants. In order to develop this model, different criteria were collected from experts within the Banavasi Range and included in the model.. The detail for the criteria included is described in the next paragraph.

The major criteria included in the medicinal plant protection model are: forest degradation status, population pressure, livestock pressure, encroachment pressure, and finally offence cases booked. The criteria used in this model can applicable only to this study area. The parameter for the same medicinal plant protection model for the other area may vary based on the problem present in that area. The first criteria forest degradation status was collected from the recent satellite image classified output, the other categories such as encroachment, population and offence case booked are from socio-economic data sources. The reason for the inclusion of these variables or criteria is based on the potential problems affecting the medicinal plants with in the study area. For example forest degradation status shows which areas have a problem of high degradation of forest, livestock pressures demonstrates how heavy grazing could affect the medicinal plants.

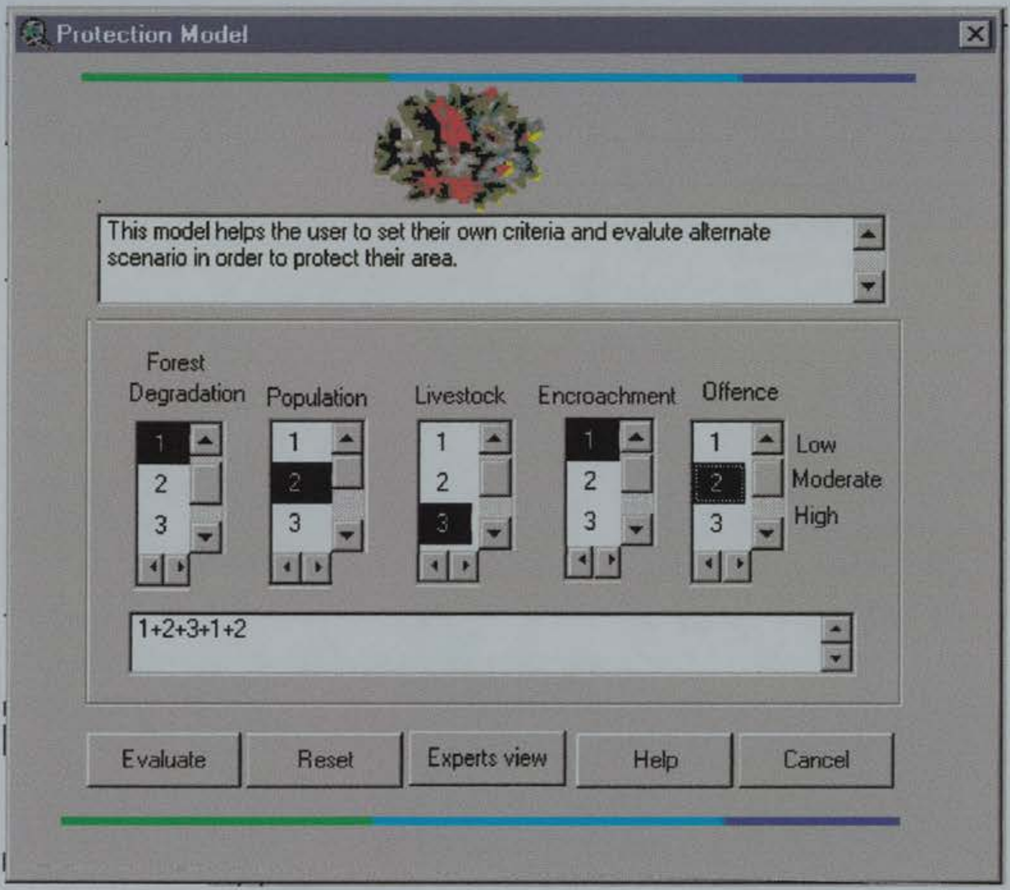


Figure 8.16 Medicinal plants Protection model interface

The data for each category were grouped into three categories with low = 1 and moderate = 2 and high = 3 (Figure 8.16) for the easy interpretation of the data. The grouping of the data is based on the problems in each criterion, for example, forest degradation status were grouped based on the status of the degradation such as severely or moderately or slightly degraded. This classification was achieved through the image processing. Once a model has been understood, the user can explore the alternatives by setting up his/her own criteria and evaluate the alternative scenarios, thus fulfilling the major DSS characteristics. The example is taken of an area which has low forest degradation, where population pressure is moderate, livestock pressure is high, encroachment problem is low and moderate level of offence cases booked (Figure 8.16). After setting the criteria, then click the evaluate button on the interface (Figure 8.16) to run the model. The user can change the criteria and run the model until he/she is satisfied the result. Then finally, the result output can be either taken as a map format from the viewer or as a table. The result output such as map production and report generator is discussed in the next section.

Step 5: Output of the results from the model

Once the user has evaluated a scenario, then he/she can use the ***Display Manger*** module to provide a printed output, using the commands to generate a formal map and the reports to assist in further planning and decision-support. These functionalities can be accessed through pull-down menus, or buttons, from the ***Display Manager*** on the main window (Figure 8.17).

Figure 8.17 Output module in RAMDSS

(i) **The Map maker**

The map maker function allows the user to create neat automatic maps. After viewing the alternatives and finalising the output, the user can select the map maker tool from the tool bar to create the map. Figure 8.18 is the sample output produced from the *medicinal plant protection model.* The map shows the villages (in yellow colour) with suitable areas for medicinal plant protection. This command automatically takes the view into the layout and places the scale bar, logo, north arrow and legend. The user has to provide the title of the layout then it creates a neat map for printing.

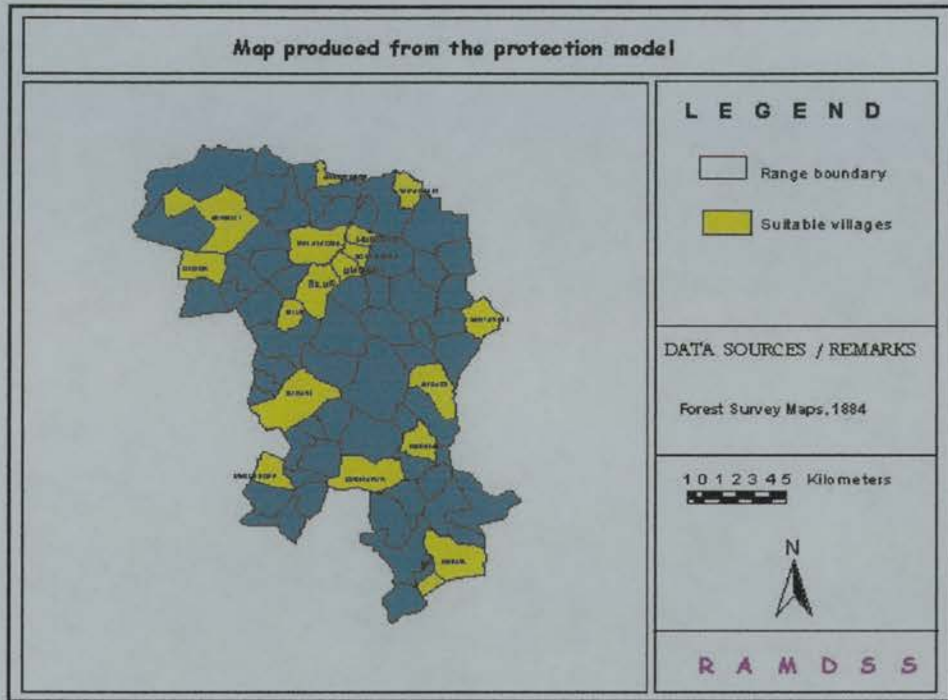
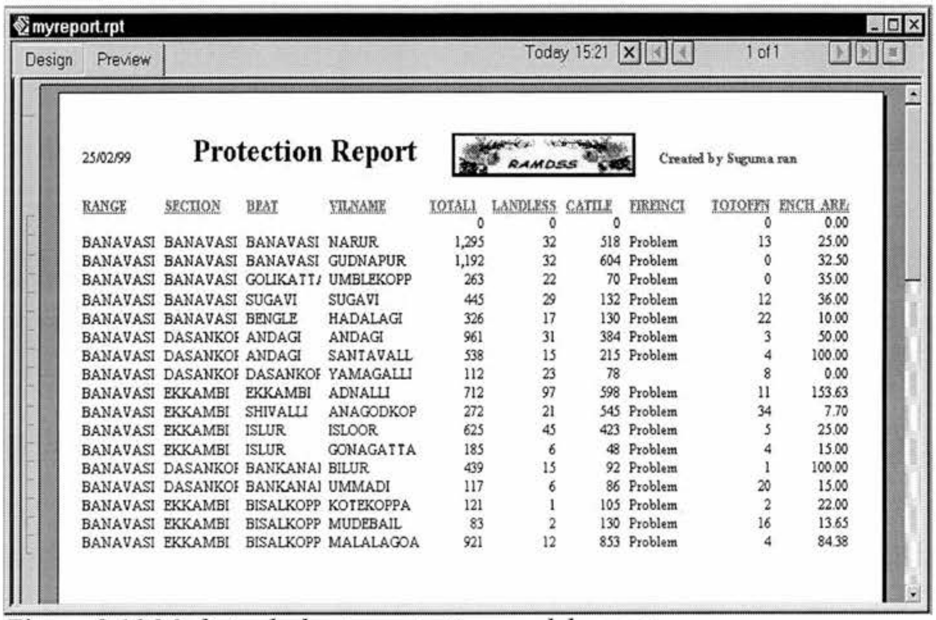


Figure 8.18 Map layout produced from the protection model

(ii) The Report Generator

Once the user is satisfied with of the modelling output then he/she can select the report generator function from the menu bar to present the output in the report format (Figure 8.19). The report generator command helps the user to create a report from the result output through the use of quick automatic wizard explanation. The report generator option allows the user to create different report format such as standard report or quick report. Figure 8.19 shows the report created for the *medicinal plant protection* model using a standard report format.

In order to help these issues covered in the whole model, Windows '***Help files***' are also created for all the models. Figure 8.20 is the screen shot of the main window Help system for medicinal plants protection model.



myreport.rpt

Design Preview Today 15:21 1 of 1

25/02/99 **Protection Report** RAMDSS Created by Suguma ran

RANGE	SECTION	BEAT	VILNAME	TOTALI	LANDLESS	CATILE	FIREINCI	TOTOFFN	ENCH ARE
				0	0	0		0	0.00
BANAVASI	BANAVASI	BANAVASI	NARUR	1,295	32	518	Problem	13	25.00
BANAVASI	BANAVASI	BANAVASI	GUDNAPUR	1,192	32	604	Problem	0	32.50
BANAVASI	BANAVASI	GOLIKATTA	UMBLEKOPP	263	22	70	Problem	0	35.00
BANAVASI	BANAVASI	SUGAVI	SUGAVI	445	29	132	Problem	12	36.00
BANAVASI	BANAVASI	BENGLE	HADALAGI	326	17	130	Problem	22	10.00
BANAVASI	DASANKOF	ANDAGI	ANDAGI	961	31	384	Problem	3	50.00
BANAVASI	DASANKOF	ANDAGI	SANTAVALL	538	15	215	Problem	4	100.00
BANAVASI	DASANKOF	DASANKOF	YAMAGALLI	112	23	78		8	0.00
BANAVASI	EKKAMBI	EKKAMBI	ADNALLI	712	97	598	Problem	11	153.63
BANAVASI	EKKAMBI	SHIVALLI	ANAGODKOP	272	21	545	Problem	34	7.70
BANAVASI	EKKAMBI	ISLUR	ISLOOR	625	45	423	Problem	5	25.00
BANAVASI	EKKAMBI	ISLUR	GONAGATTA	185	6	48	Problem	4	15.00
BANAVASI	DASANKOF	BANKANAI	BILUR	439	15	92	Problem	1	100.00
BANAVASI	DASANKOF	BANKANAI	UMMADI	117	6	86	Problem	20	15.00
BANAVASI	EKKAMBI	BISALKOPP	KOTEKOPPA	121	1	105	Problem	2	22.00
BANAVASI	EKKAMBI	BISALKOPP	MUDEBAIL	83	2	130	Problem	16	13.65
BANAVASI	EKKAMBI	BISALKOPP	MALALAGOA	921	12	853	Problem	4	84.38

Figure 8.19 *Medicinal plants protection model* report

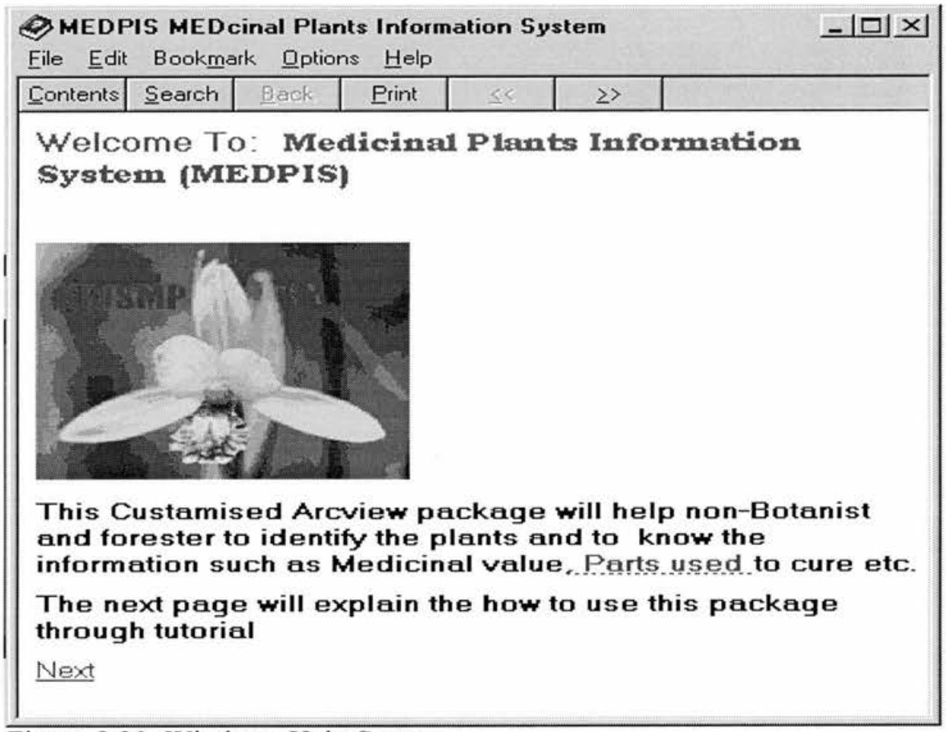


Figure 8.20. Windows Help System

The ***Help files*** can be directly accessed through pull-down menus or buttons on the main window interface. The help files are explained in the detail and step by step with simple hypertext.

8.3. The evaluation of Medicinal plant protection model.

Evaluation is the activity of verifying the various system specifications and models produced during the software development process (Bender, 1996). As mentioned earlier, the design of the RAMDSS was purely based upon user needs (see Chapter 5). However, in order to get the users' opinions on the usefulness and friendliness of the RAMDSS prototype, a user evaluation has been performed at different stages. The evaluation of each of the modules in this project was an iterative process with the end user. This was achieved in three different stages, i.e. a data collection stage, a data analysis stage and a data display stage. The following example describes how medicinal plant protection model was evaluated with end user(s) and the extent to which it fulfilled the user(s) requirement.

As mentioned earlier, the overall objective of the medicinal plant protection model is to develop a model, which can help the forest Ranger to conserve the medicinal plants in the Banavasi Range. In order to achieve this goal, the evaluation was carried out with forest officials within the Karnataka Forest Department. The first stage, namely data collection, was demonstrated to the user and the feedback from different respondents was collated and then included in the model during the field visit in KFD. The main feed back involved the development of a field data form instead using a simple spreadsheet. Developing an interface with the Microsoft Access database (see Section 8.2.6) fulfilled this.

The second and third stages, namely data display and data analysis were developed and evaluated during the field visit and also through consultation with Dr Mike Harrison, who was the principal investigator on the DFID funded project. Very little change requested at the data analysis stage. However, there was some feedback on the data analysis stage. The respondents wanted the model to be useful for both technical and non-technical potential users. In order to support the non-technical planner, a Knowledge Based System was developed and linked with RAMDSS (see Section 8.2.7).

A detailed help file and simple tutorial were also requested in order to facilitate understanding of the models. This was developed using Windows help file and was then included in the RAMDSS. Although the model is operational, it has a few limitations - such as static parameters or fixed predefined criteria, and it is restricted to this study area although the principles are likely to have wider applicability. The generic medicinal plant protection model was not achieved because of time and financial constraints. The possible solutions for these problems are discussed in detail in the section on system limitations and future research (See Chapter 9).

8.4. Summary

This chapter has demonstrated how the RAMDSS can provide information that can help the manager to undertake the planning process in a daily basis in the study area. The functionality of RAMDSS includes three main modules the ***Data Manager***, the ***Model Manager*** and the ***Display Manager***. The ***Data Manager*** assists the manager to collect, maintain, query and visualise the existing database, Where as, the ***Modal Manager*** assists the user to undertake a regular planning process working through the models. The procedure for modelling alternative scenarios in RAMDSS is divided into five major steps namely: - setting up the database, selecting a required model, user level choice, setting model criteria based on experience or expertise provided by system and evaluating the alternatives, and finally report generation and map production. The RAMDSS benefits the inexperienced user by providing some assistance from expert knowledge integrated into the system through the coupling of ArcView with a Knowledge Based System. The operation of the system is explained with an example of a model for the conservation of medicinal plants.

Chapter 9: Discussion and Conclusion

The main goal of this thesis is the development of a DSS for forest planners as a means of improving forest management. The present chapter considers the extent to which RAMDSS can be said to meet the user requirements articulated in Chapter 5 and also fulfil the SDSS requirements indicated in Chapter 2. Evaluation of the success of RAMDSS in meeting these requirements is essential because it assesses the success of the prototype and should demonstrate the importance of the system to potential users. The final section forms a summary conclusion.

In the first chapter, several research questions related to the development of DSS for forest planning were raised. For example, what are the problems of current forest planning methods or planning tools? Why is there a need for an integrated DSS in forest planning? How could such a support system be developed? (Chapter 1). The answers to these questions were presented and analysed in chapters 2-8.

9.1. The need for a DSS in forest planning

One of the major problems faced by today's forest manager is related to the planning process. Forest planning and management involve extremely complex and decisions, whether made by legislatures or planners, and require information on a wide variety of resources. Data are needed for example on forest inventories, socio-economic and other information relating to the local stakeholders and physical parameters such soil, geology, geomorphology and land cover (Chapter 1, 2 and 5). Present day methods are not able to handle these issues very well because of the large volume of information and the complexity of the interrelations (see chapter 1). In order to handle the variety of data and also able to solve more critical environmental and resource management problems, it is argued that there is an urgent need for better tools. The rapidly developing field of information technology DSS can provide the necessary "machinery" (Fedra, 1995). However, the Decision Support Systems (DSS) will not supply the answers to tough management questions, hence the term *support system*. The system can only gather together and analyse the information needed to aid managers in making better informed and sound decisions and to plan ahead far more rapidly and efficiently.

Decision Support Systems are described as analytical tools, which integrate many sub-systems, including Geographical Information Systems (GIS), a user interface, Data Base Management Systems and Knowledge Based Systems (KBS) (Chapter 2 and 3). An integrated DSS can be used to assist the decision-maker in assessing the inter-relationships and potential effects of a policy or decision. Several authors have argued that the biggest challenge in integrated DSS seems to be the incorporation of new information technologies and more or less mature formal methods of analysis into existing institutional structures and societal processes. In other words, the hurdle to be overcome is putting these tools to work in practice. (Fedra. 1991; Zhu, 1995; Rias et al., 1997).

The present research has made an attempt to develop an integrated DSS to improve planning and decision-making processes by providing useful and scientifically sound information in accordance with predefined requirements. A case study from the Banavasi Range of the Western Ghats was used to illustrate the result. The choice of study area is justified in Chapter 4. The major contributions of RAMDSS to forest planners can be summarised as including: an efficient way of collecting, storing and updating data for effective planning than traditional methods; the construction of a simple interface to query and visualise the existing data in order to understand the different data sets; several models for the interactive exploration of different strategies in order to address effective planning approaches (greater flexibility than traditional methods), an opportunity for novice users to learn from the Knowledge

Based System; and a powerful and automatic report generator for the rapid and effective production of results. Each of these features is now discussed in greater detail.

The first step in forest planning is to develop and manage the database. This includes data acquisition, data maintenance and data analysis. Both building a DSS and forest decision-making involve collection and maintaining the data (data management system in DSS), analysing the data (model management in DSS) and presenting a result (Feng and Chen, 1995; Denshem, 1992). Keeping the importance of these issues in mind, the development of SDSS for forest planning was divided into five major components:- Data management, Model management, Displaying the results, User interaction and using an Integrated approach. Armstrong and Densham (1991), have also grouped these characteristics into five key components in order to develop a spatial decision support system. They distinguished (1) a Data Base Management System (DBMS); (2) a Model Management System (MMS), including analysis procedures; (3) a display generator; (4) a report generator and (5) user interface. The next section discusses all five key components involved in the development of DSS in this study.

9.2. Managing the data

This includes data acquisition from different sources, data maintenance and data analysis for effective decision-making and improved forest planning and management. These issues are discussed in the chapter 2 and chapter 5. The RAMDSS fulfils these issues through the *Data Manager* module available in the system.

The first contribution of this research is related to the development of a computerised method for maintaining the database. The new system allows the planner to collect store, update and maintain the data sets easily and more effectively than the traditional methods (user requirement 1 and 2; SDSS requirement 1 and 2). The reason for including this option in the system is the importance of data in forest planning and decision-making. The databases required for developing a spatial decision support system specifically for forest management may include a variety of data because of the complexity of the processes involved in planning (Susilawati and Weir, 1990). These processes require up-to-date spatial and non-spatial data, acquisition of many kinds of specialist knowledge and techniques from various related disciplines (Puttee, 1989; Funnpheng et al., 1994). These issues were effectively and efficiently incorporated into the module *Data Manager* in the RAMDSS (See Chapter 7).

The present system can collect spatial, non-spatial and knowledge base from the different sources. The spatial data are stored in GIS (Arcview and ArcInfo GIS); attribute data stored in RDBMS and knowledge stored in Knowledge Based System. The spatial formats supported by the system include Arcview shape file, ArcInfo format, AutoCAD and Intergraph, Mapinfo and ASCII format, whereas the non-spatial data sets include Info, delimited text, mdb of MS-Access and dbf. The need for this separation of data is based largely on the fact that spatial data has been most efficiently accessed through spatially indexed data structures managed by an optimised data storage mechanism, whilst on the other hand, the relational structure was ideally suited to attribute or non-spatial data (Gill and Leckie, 1996). Although the database is kept separate for maintenance purpose, it can be linked through ODBC (SQL connector) whenever necessary for planning purposes. Several authors used the same approach in their studies (Romanek, 1998; Gill, 1998).

One of the biggest challenges of data management is data "currency" (Nelson, 1999). Corrie et al. (1994) also explained that ' outdated information is useless information' for effective decision-making. In order to achieve this ideal, information should be kept up-to-date (user requirement 1 and SDSS requirement 1). This is achieved in the RAMDSS through incorporating satellite remote sensing images for spatial data because remote sensing provides a means of collecting areal information repeatedly, on a regional or global scale, particularly in remote areas which are difficult to access by any other means. They are cost effective and offer real time data acquisition compared to traditional methods. Malis and Vezina (1999) have pointed out that one of the biggest issues facing foresters today world-wide is the need to maintain and update data and this can be achieved by using high-resolution satellite images. The resolution and usefulness of remotely sensed data is likely to increase markedly over the next 10 years. Furthermore, several researchers have explained the importance of incorporating RS into DSS for several other types of application (Crain, 1992; Schultink, 1992; Fedra, 1994 and 1995; Rajan, 1995; Llewellyn et al., 1996; Badji and Dautrebande, 1997; Moran et al., 1997). However, in the present system, updating of non-spatial data is only carried out by the traditional field data collection. There are new approaches also emerging in order to collect the non-spatial data. For example, Bourgeois and Chambers, (1999) introduced speech data collection through speech recognition techniques for the rapid collection of forest inventory data.

Although the present study uses satellite imagery for updating the forest land cover map, other maps such as soil, geology and geomorphology are not up to-date because of time or non-availability of data in the study area (see chapter 7). This can be expanded in time and added to future extensions of research. Finally, the RAMDSS also provides a powerful query capability (user requirement 2 and DSS characteristics 2). The system allows the manager to synthesise or explore the existing data sets into useful information in order to use in the decision-making. This might include for example, finding out the highly populated villages in the study area or locating fire-watching towers.

The above information covers mostly data-related issues such as collection, storing and querying the existing data. The next paragraphs demonstrate how the data can be manipulated or analysed for taking timely and appropriate decisions.

9.3. Analysing the data (Modelling management)

Analysing collected data through modelling is another important aspect in effective decision-making in forest planning. The modelling of environmental processes is of major importance in many studies of the natural physical environment because it involves implementing the system's manipulation, modelling and simulation capabilities (Corrie et al., 1994).

In the present system, a manipulation and modelling capability was included with a user-friendly and simple graphical user interface (user requirement 3 and 4 and DSS requirement 2, 4 and 5). In order to handle the analytical capability with in RAMDSS, several static models were included based on the user requirements through a dialog designer and Avenue programming (see chapter 7). However, the models in this study provide a solution for simple problems. Examples include finding out the suitable areas for the conservation of wild life, bio-diversity, or protection of forest fire etc. These models can provide planners with an ability to evaluate alternatives and support the decision-making process. They are capable of extensive refinement in the future.

Shmoldt and Martin (1986), Densham and Goodchild (1989), Fedra (1995), Reynolds (1996) and Ray et al. (1999) have pointed out that an SDSS " should incorporate knowledge used by expert analysis to provide assistance to inexperienced users and are also designed to solve ill-or semi-structured problems. RAMDSS can achieve this goal partially through its knowledge base module (User requirement 9). The system assists the novice planner to take effective planning through 'expert advice' which is stored in the Knowledge Based System (see Chapter 6 user requirement 9). User requirement 10 and DSS requirement specifies that the system should provide information about each model and system. This is achieved by the use of the hypertext windows Help file (chapter 6). This provides a description for different models on how they can used for the planning and decision-making.

Simulation and mathematical models are not included in this thesis although they can contribute to effective decision-making. The simulation models help the planner to understand better the ecological and physical processes involved in forest planning and for the prediction of forest changes (Corrie et al., 1994). The present implementation does not support simulation models. This may be a topic for future research. Another problem, which was not explored here, involves dynamic or generic models. The models in this thesis treat time as a constant and model variables do not vary over time. For example running the medicinal plant protection model involves only a set of fixed variables and cannot be changed. This is also an area which could be modified in future developments of the RAMDSS.

9.4. Presentation of results

As mentioned earlier, visualisation techniques have proven invaluable in the presentation of analysis results (Church et al, 1994; Bishop, 1997). They can be crucial in supporting DSS users to gain new insights into the structure of their problems, by generating different views of the decision situation and by exploiting their own visual skills so that they can recognise meaningful alternatives and strategies during the problem-solving process. In addition, the ability to visualise the information over space and time adds perspective to the scientists' and the decision-makers' understanding (Angehrn and Luthi, 1990; van Voris et al, 1993; Bishop, 1997; Wherrett, 1996).

The present prototype has the capability to view results in the form of maps, 3-D animations, graphs, images, reports and tables. The presentation tool in RAMDSS provides additional insights to results, which would otherwise be displayed as text or numbers. The RAMDSS *Display Manager* module facilitates automatic map production and provides an easy report generator with a simple interface. The 3-D animations, images and video clips can be viewed from the visualisation command available in the *Data Manager* module.

The results of the *scenario* evaluation performed by the models or through queries must be displayed to the user in a manner that makes the results easy to understand and also easy to explain to others (NCGIA report, 1995). Armstrong and Densham (1990) mentioned that display facilities in DSS should provide high-resolution cartographic displays, specialised graphics for depicting the results from analytical models and the full range of tabular reports normally associated with each of the above. The present system provides most of these facilities including traditional tools for visual communication of resources including line charts, sketches and photographs and also new tools such as video clips, 3-d models and animations.

9.5. User interaction

The Graphical User Interface (GUI), defined as a combination of windows, menu and icon selections is designed to guide the user quickly and easily through the program (NCGIA report, 1995). GUI also allows the dynamic linking of existing models from the Model management to the Data management. The RAMDSS interface is assembled in such a way that a planner always has the impression that he/she is interacting with a single and coherent system. The UserInterface provides the method by which planners interact with a program on a visual level and it is the integrating mechanism for the data, models and displays. According to Armstrong and Densham (1990), the user interface must be easy to use if it is to be effective in decision-making; have icons which can be used to represent system capabilities; allow the user to select parameters, data, and output easily and intuitively; assist the user to visualise more easily the processes represented within the model.

The present RAMDSS provides all these characteristics with a simple and effective interface and developed through Arcview GIS and Avenue programming combined with the Dialog designer extension available within Arcview GIS. It allows the user to interact easily with different models through either pull-down menu or via buttons provided in the tool bar (Chapter 6). Each model has simple dialog boxes with easy click buttons. The pull-down menus contain the major functions of RAMDSS including: 1) Data manager, which provides the user with the capacity to collect, maintain, query and visualise the existing data; 2) Model Manager, which allows the user to view the data related to input for models parameters; 3) Display manager, which allows the user to view parameters spatially and to select the output for viewing results; and 5) Help, a hierarchical help facility, which describes in detail all the options in the programme.

9.6. Integrated DSS approach

The above discussions of the different technologies show that each technique or technology contributes collectively to the successful development of a DSS for forest planning and management. It seems obvious that no single method can address all these requirements credibly and satisfactorily (Fedra, 1990; Mejía-Navarro and García, 1995). The full benefits of the tools mentioned above are obtained when they are used in combination as functional components of " an integrated information System" (Bronsveld et al., 1994). The Integrated Decision Support approach combines different software such as modeling techniques, analysis techniques, complex data, Geographic Information Systems (GIS) and Graphical User Interfaces (GUI), Knowledge Based Systems with software engineering to create Decision Support Systems for natural resources management (Fedra, 1995; and Mejía-Navarro and García, 1995).

The integration of these technologies has the potential to improve greatly the efficiency as well as the power of SDSS. In order to develop an efficient single approach, the present study integrates a GIS, RDBMS, KBS, Visualisation and GUI for the development of a single system termed RAMDSS in this research (see chapter 6). Several researchers have earlier suggested the importance of integration of different techniques into a single system (Fedra, 1991; Fulcher et al., 1994; Prato et al., 1995). Theoretical possibilities have been extensively and adequately covered in the literature (Craig and Moyer, 1991; Densham, 1991; Moon, 1992; Enche, 1994; NCGIA, 1992; Zhu, 1994). Bronsveld et al., (1994) suggested that when integrating many tools, managers should also bear in mind the problems such as funds, trained personnel, algorithms for combining data from the different sources.

The integration in RAMDSS includes three main methods:- Arcview-Sictus Prolog link through DLL, Arcview-MS-Access link using ODBC and coupling Arcview-Modelling via avenue programming with Dialog designer extension (see Chapter 5). The present study, although Arcview GIS, integrates some of the tools such as the image processing with *'Image analyst'* extension, simple modelling (through *'spatial* *analyst'* extension and static models), KBS to support the novice user and report generator through the *'report writer'* extension; however, it lacks powerful generic modelling and is unable to handle ill-structured data. These points are discussed below.

9.7. System Limitations and Future Research

The RAMDSS is developed as part of the DFID funded project to the Karnataka Forest Department in India. The system first stage is implemented and operational. The second phase will be implemented over the next five years. Although it is working, the current implementation has the following limitations, which can be the areas to be addressed in future research:-

- Although the present prototype handles spatial and non-spatial formats supported by Arcview GIS, it does not support most of the other common formats. The spatial data supports include ArcView Shape, ArcInfo, Autocad etc. and for non-spatial data formats such as dbf, Info, delimited text, mdb etc. This can be extended either through writing Avenue codes to convert or linking to a commercial standard convertor.

- Another limitation of the present system is that of data quality. Some of the data sets are very old, of poor quality and not accurate to use in effective planning. For example, the geology and geomorphology maps are small scale and limited value (Chapter 5). But, because of the factors such as non-availability, cost and time updating could not achieved in the present research.

- Although a Knowledge Based System assists the novice user in taking better decisions it does not at present handle the uncertainty in data, which is one of the powerful applications of KBS. Future study could look into this aspect as well.

- Although the models included in the system are simple and based on user requirements, they do not allow the user to change the variables and furthermore, they do not currently have simulation or mathematical modelling capability. The static models such as fire protection, wildlife protection, and plantation models available within the system have fixed sets of criteria, which are derived from expert opinion in the study area. The models should be generic because forest areas are changing very rapidly through many dynamic factors. It is hoped to develop a generic modelling capability through the modelling software such as STELLA, or AME amongst the further research aims.

- Another limitation relates to the System platform. Although the present system fulfils the user requirements that the system should be PC based, it does not support other platforms such as Unix and Macintosh. This can be achieved at a later stage if required.

The above discussion demonstrates how the DSS is an important tool for forest planning and management and that the integrated packages which constitutes the system do, in practice, achieve the objectives set out in the beginning of the research.

9.8. Conclusions

The continued forest losses throughout the world have resulted in the need for forest planners to take urgent action for conserving and sustaining forest resources, especially tropical forests, through proper planning and management. The proper forest planning requires a more sustainable or multiple goal approach than the traditional single goal approach. In order to achieve this goal, it is necessary to collect timely information, and need to integrate a large amount of spatial and non-spatial information for complex analysis along with accumulated existing knowledge from several disciplines. One promising approach to these problems is to develop suitable Spatial Decision Support Systems (SDSS) at various levels of decision-making.

It has been the aim of this study to integrate the different technologies into a single functional computer based interactive SDSS targeted specifically at the forest Ranger level and as a result the development of Range Management Decision Support

System (RAMDSS). The development of RAMDSS involves the collection of user and system requirement, followed by design and implementation of the system. Requirement analysis typically involved in two stages: identification of potential users or stakeholders, and elicitation from the users of the features they would like to see included in the final software. After collecting the user requirements, the required tools and techniques were identified and physical design of the system was developed.

The implementation of the RAMDSS was achieved using different softwares such as Arcview and ArcInfo GIS for the manipulation of spatial data, Microsoft-Access to handle non-spatial data, Erdas Imagine for analysing the remote sensing data, Sicstus Prolog to organise the experts knowledge and finally, development of simple GUI using dialog designer and Avenue programming. The integration of these software packages have been achieved through a Dynamic Link Library, Data Dynamic Exchange, and Open Data Base Connectivity.

The RAMDSS integrated SDSS developed in the study can assist the planner in the daily planning process. The RAMDSS, makes complex and technical information and knowledge available to decision-makers through a user-friendly graphical user interface. It allows the user to: organise information based on existing data and scientific knowledge, design, alternatives and access consequences of a new range management plans or policies and evaluate and compare alternative Range management schemes.

The functionality provided by the RAMDSS, allows the Forest Ranger or other to collect and maintain the database easily and effectively as well as to analyse these data and model alternative *scenarios*. In order to handle these issues, the system has three major modules: *Data Manager, Model Manager* and *Display Manager*.

The first module, D*ata Manager,* provides four useful functions for the planner and manager. It includes data collection, data maintenance and data query and data visualisation. The data collection function allows the user to input the collected data through a simple and easy interface, whereas the data maintenance function help the user to maintain the existing data sets. In addition, the data query function assists the Ranger to explore the existing data sets through a simple query system and ultimately help in decision-making. Finally, data visualisations aid the Ranger to view the existing data sets as well as the results from the data query functions.

The second module developed in the RAMDSS is *Model Manager*. The Model Manager is a planning tool that enable Rangers (and others) to evaluate forest planning strategies by addressing particular problems. Different models were developed, in order to help the Ranger to take more informed and timely decisions. The static models are divided into two sub-modules such as *Production* and *Protection manager*. The Production module helps the user to find out the areas suitable for the generation of revenue from the study area, for example collection of dead and fallen timbers, NFTP's, or tourism. The protection sub-module assists the user to select suitable areas for effective protection. Other models dealt with issues such as medicinal plants, encroachments, wildlife or fire. Each model has the capability to deal with or allows the novice user to learn the different planning processes, through interactive learning via the Knowledge Based System and Help System.

The final module, *Display manager,* has been developed to provide easy report and map production after running a particular model or query. In order to achieve this, there are two functions added to this module namely, map-maker and report generator. The main aim of these functions is to provide the Ranger with a simple, semi-automated method for producing printed output of query and modelling results in maps as well as a report form. The next section concludes with a brief note on a lesson learned from the development of RAMDSS and its limitations.

The major objective of the overall project is to develop a system for forest planners in order to take better forest planning in the Banavasi Range of the Western Ghats. The objective of the project mentioned in the chapter 1 was achieved through the development of RAMDSS. The development of RAMDSS includes an integration of different components such as Remote sensing, GIS, Knowledge Based System modelling, report generator and simple user interface. The major obstacle faced during the development process is the speed of technology. For example, during the selection of software (Arcview) for the development of RAMDSS in 1996, it does not have any report writer module. This module was written using 'avenue' programming in the project spending two to three months, but by the time the project ended, the Arcview came up with an extension called 'Report writer' which is better version of the module compared to code written by the author.

In addition, although the system and methodology is operational, the system has several limitations such as it supports only a few data formats, existing data in the system is of poor quality, the KBS does not handle uncertainty, the prototype has only simple and static models and faced a problem with the speed of technology. The future direction of RAMDSS development will address these constraints. Despite these limitations, the RAMDSS works and has already been implemented in the Banavasi Range. In addition, though the present methodology developed was designed for a specific area, it can be transplanted into other geographical areas such as other ranges or divisions. The Karnataka Forest Department of India is already expanding this methodology for the other Ranges in the Sirsi Division.

The future of the forests is the future of Mankind. Their survival is our survival. Let us save one of Earth's greatest treasures

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Appendix -1: Arcview and Sicstus link

```
// Avenue_Interface.cpp : Defines the initialization routines for the DLL.
//

#include "stdafx.h"
#include "Avenue_Interface.h"

#ifdef _DEBUG
#define new DEBUG_NEW
#undef THIS_FILE
static char THIS_FILE[] = __FILE__;
#endif

//
//	Note!
//
//		If this DLL is dynamically linked against the MFC
//		DLLs, any functions exported from this DLL which
//		call into MFC must have the AFX_MANAGE_STATE macro
//		added at the very beginning of the function.
//
//		For example:
//
//		extern "C" BOOL PASCAL EXPORT ExportedFunction()
//		{
//			AFX_MANAGE_STATE(AfxGetStaticModuleState());
//			// normal function body here
//		}
//
//		It is very important that this macro appear in each
//		function, prior to any calls into MFC.  This means that
//		it must appear as the first statement within the
//		function, even before any object variable declarations
//		as their constructors may generate calls into the MFC
//		DLL.
//
//		Please see MFC Technical Notes 33 and 58 for additional
//		details.
//
```

```
/////////////////////////////////////////////////////////////////////////////
// CAvenue_InterfaceApp

BEGIN_MESSAGE_MAP(CAvenue_InterfaceApp, CWinApp)
	//{{AFX_MSG_MAP(CAvenue_InterfaceApp)
		// NOTE - the ClassWizard will add and remove mapping macros here.
		//    DO NOT EDIT what you see in these blocks of generated code!
	//}}AFX_MSG_MAP
END_MESSAGE_MAP()

/////////////////////////////////////////////////////////////////////////////
// CAvenue_InterfaceApp construction

CAvenue_InterfaceApp::CAvenue_InterfaceApp()
{
  liNumExtant=0;
  b_SPinitialised=FALSE;
  b_prologLoaded=FALSE;
}

/////////////////////////////////////////////////////////////////////////////
// The one and only CAvenue_InterfaceApp object

CAvenue_InterfaceApp theApp;

// Functions added to interface w. ArcView/Avenue
int mult ( int X, int Y ) {
	return X*Y;
}

int factorial ( int X ) {
  long value;

  SP_put_integer( theApp.tr1, X );
  SP_put_variable( theApp.tr2 );

  SP_query( theApp.pred_factorial, theApp.tr1, theApp.tr2 );
  return (SP_get_integer( theApp.tr2, &value )==0) ? -1 : value;
}

/*
char * start ( void ) {
  char buf [1024];

  SP_put_variable( theApp.tr1 );
```

```
  SP_query( theApp.pred_start, theApp.tr1 );
  return (SP_get_list_chars( theApp.tr1, (char**)&buf )==0) ? -1 : buf;
}
*/

// END Functions added to interface w. ArcView/Avenue

// Sicstus interface fns.
SP_MainFun *sp_pre_linkage[] = {
0};

char *sp_pre_map[] = {
0};
// END Sicstus interface fns.


BOOL CAvenue_InterfaceApp::InitInstance()
{
        /* These are for initialisation of SP */
        int argc=1;
        char* argv="fake_name";

  try {
    if( b_SPinitialised==FALSE ){
      if ( SP_initialize(argc,&argv,NULL)!=SP_SUCCESS ){
        MessageBox( NULL, "Sicstus DID NOT initialise correctly",
          "RBCLM warning", MB_ICONEXCLAMATION );
        //return FALSE;
      } else {
        MessageBox( NULL, "Sicstus HAS initialised correctly",
          "RBCLM information", MB_ICONINFORMATION );
        b_SPinitialised=TRUE;
      }
    }

    // Load the compiled prolog code
    if (SP_load( "m:\\prolog\\factor.ql" )==SP_ERROR) {
      MessageBox( NULL, "iden.ql didn't load",
          "RBCLM information", MB_ICONINFORMATION );
      return FALSE;
    }


    /* Instantiate the SP_term_ref's */
```

```
    tr1 = SP_new_term_ref();
    tr2 = SP_new_term_ref();
    tr3 = SP_new_term_ref();
    tr4 = SP_new_term_ref();
    tr5 = SP_new_term_ref();
    tr6 = SP_new_term_ref();
    pred_factorial = SP_predicate("factorial",2,"");
    if ( pred_factorial == NULL ) {
      MessageBox( NULL, "pred_factorial didn't load",
           "RBCLM information", MB_ICONINFORMATION );
      return FALSE;
    }
// Initialisation of SP_pred_ref's done in loadProlog, after *.ql file is loaded.
    return CWinApp::InitInstance();

  } catch( CException ex ) {
                TCHAR       szCause[255];
                CString strFormatted;

                ex.GetErrorMessage(szCause, 255);

                // (in real life, it's probably more
                // appropriate to read this from
                //  a string resource so it would be easy to
                // localize)

                strFormatted = _T("Exception in InitInstance. Cause:");
                strFormatted += szCause;

                AfxMessageBox(strFormatted);

    return FALSE;
  }
}
```

Appendix-II

Village Survey for Range Management Planning

1. Village-wise Socio-economic information

Surveyor information

Completed by	(BG)	Date	
Checked by	(SF/RFO)	Date	

Administrative Information

Range		
Section		
Beat		
Village name		
Number of hamlets		
Names of hamlets	1	4
	2	5
	3	6

Land use Information

Total Village	Total Section No.	Total Beat No.	Forest Area	Agriculture	settlements	Non Forest	Misc.
76	3	11					

Population Information

	Male	Female	Total			Households
Adults					Scheduled caste	
Children					Scheduled Tribe	
Total					Other caste	
					Total	

Land Holdings

			Number of households
Large farmers	(>10 ha)		
Medium farmers	(2-10 ha)		
Small/marginal farmers	(<2 ha)		
Landless			

Occupations

Artisans	Resident households	Migrant households	Total households
Basket-makers			
Brickworkers			
Potters			
Carpenters			
Blacksmiths			
Other			

Literacy

	%
Male	
Female	

Local Institutions

	Yes/No
Schools	
Hospitals	
Electricity	
Misc.	

Livestock

Cattle	
Goats	
Buffao	
Sheep	
Total	

Local Institutions

Self-help group (SHG)	
Co-operative	
Youth group	
Women's group	
NGO	
Temple Committee	

VFC Information

If yes:	
Date of formation	
Date of MOU	
Number of members	
If no:	
Is there any interest in JFPM? (Yes/No)	

Wood saving devices

	Number
Bio-gas plants	
Smokeless Chulas	
Solar cookers	

2. Forest Inventory Data

Area statistics

Village Area (*from village accountant*)

Total village area (acres)	
Total forest area (acres)	

Forest Area (*from village forest register*)

Minor forest (acres)	
Reserved (proper) forest (acres)	
Betta (acres)	
Total forest area (acres)	

Village Area *from village satellite data*

	Ha.
Evergreen	
Semi - Evergreen	
Moist - Deciduous	
Dry - Deciduous	
Plantations	
Non - Forest	
Total forest Area	
Total Village area	

Special Privileges

From Village forest register

Village name	Description of product/privilege

KFD Infrastructure

	Number in village
Checkposts	
Depots	
Beat office	
Section office	
Nursery	
Watchtower	

Fire Incidence

Problem or no problem?
No.

Possible reasons

Forest type

Tick appropriate box for each of the Forest Survey number

Forest Sy No.	Evergreen	Semi-evergreen	Moist deciduous	Dry deciduous

Forest Condition

F Sy No	canopy Density <25 %	25-40%	>40%	Natural regeneration abundant	good	scarce	none	Eupatorium/ lantana invasion >50%	25-50%	<25%	none

Plantation information

Existing Plantations Future plans										
F Sy No	Year planted	Area Ha.	Species planted	Amount spent	Which scheme	Location in map	survival %	Available area	Amount required	Soil report Ssp report

Nursery information

Forest Sy No	Area	Species available	Number	Location in map	Age of saplings

Medicinal plants

Forest Sy No/ Village	Location in map	Species available	Parts used	remedy	Misc.

NFTPs

This information is for the entire village and not VFSNwise

Year	Products	Quantity	Families benefited	Tender No.	Income

Logging and extraction

	quantity extracted	year of last extraction	estimated current availability (cum)	Year assessed
timber (dead)	cum		cum	
fuelwood (dead)	cum		cum	
bamboo	lengths		lengths	
cane	lengths		lengths	

Offence cases

From beat records

	1996-97	1995-96	1994-95	1993-94	1992-93
Number of cases booked					

Urban fuel-wood supply

	number of loads	kg/load	kg per year	To which town	Residence of head-loader or cart-loader
Bicycles/cart loads					
Head-loads					

Encroachment

Village	VFSN	Location in map	Area encroached	En. House holds No.	Purpose Argi. / House / etc.

Non-forested areas

	Area (acres)	VFSN
KFDC leased		
Disforested		
Mines, quarries, power-lines, dams		
SC/ST private lease		

Seasonal graziers

Yes/No [ ] If yes, from where? [ ]

Conservation areas and ecotourism areas

Conservation areas (tick and mark on map)

Sanctuary	Sacred grove	Kan	Nature reserve

Eco-tourism areas

falls	temple	viewpoint	caves	Rocks	Other

Plot study

Vill.	FSRN	soil type	Species 10 /10 m	Dominant	Height	DBH	5 / 5 m	Species	Regeneration	Mis.

Soil Condition

: Tick appropriate box for each of the Forest Survey number

F.Sy. No	Poor	Average	Good

Slope from DTM

Tick appropriate box for each of the Forest Survey number

Forest Sy NO	0 Flat <2%	1- Moderate 2-10%	2- Steep 10-30%	3- Very steep >30%

Soil erosion status:

tick one box

Forest Sy. No	0 No erosion (Good soil)	1 Some erosion (compact or exposed soil)	2 Severe erosion (laterite, rocky, little or no soil)

Appendix- III: Non-spatial database

SECTION	BEAT	VILNAME	VIL_C	NOHAMLE	MALE	FEMALE	TOTAL1	POPTVA	POPTFA	SC	ST
BANAVASI	BANAVASI	MUGAVALLI	10	0	441	479	920	2	4	0	0
BANAVASI	BANAVASI	CHIKDUGLI	4	0	13	4	17	0	0	0	0
BANAVASI	BANAVASI	KALKOPPA	6	0	219	220	439	4	7	36	0
BANAVASI	BANAVASI	NARUR	11	2	662	633	1295	2	4	48	0
BANAVASI	BANAVASI	BHASI	3	0	638	610	1248	2	3	58	0
BANAVASI	BANAVASI	BANAVASI	1	2	2903	3460	6363	9	45	78	0
BANAVASI	BANAVASI	TIGANI	12	1	840	869	1709	8	14	98	0
BANAVASI	BANAVASI	KADAGOD	8	0	153	128	281	1	6	0	0
BANAVASI	BANAVASI	MADHURVAL	9	1	393	394	787	2	5	0	0
BANAVASI	BANAVASI	GUDNAPUR	5	1	584	608	1192	2	9	2	0
BANAVASI	BANAVASI	AJJARNI	2	0	578	469	1047	3	32	45	0
BANAVASI	BANAVASI	KANTRAJI	7	0	508	515	1023	2	33	48	0
BANAVASI	GOLIKATTA	KOGODU	17	0	65	61	126	1	1	0	0
BANAVASI	GOLIKATTA	SAHASRAHA	22	0	155	147	302	1	1	5	0
BANAVASI	GOLIKATTA	KALLI	16	0	143	154	297	1	1	0	0
BANAVASI	GOLIKATTA	UMBLEKOPP	20	0	128	135	263	1	1	8	20
BANAVASI	GOLIKATTA	MUNDAGEHA	18	0	79	81	160	1	1	0	0
BANAVASI	GOLIKATTA	GOLIKATTA	78	0	128	135	263	1	2	2	0
BANAVASI	GOLIKATTA	NAVANAGER	19	0	187	179	366	1	1	10	0
BANAVASI	GOLIKATTA	VADDINKOP	21	0	135	117	252	1	1	0	0
BANAVASI	GOLIKATTA	KALGUNDIK	15	0	139	142	281	2	2	0	0
BANAVASI	GOLIKATTA	GADAGERI	14	0	274	281	555	2	3	20	0
BANAVASI	SUGAVI	SUGAVI	23	3	0	0	445	2	0	0	0
BANAVASI	SUGAVI	HALSINKOP	26	0	82	72	154	2	2	2	0
BANAVASI	SUGAVI	KANKOPPA	27	0	84	74	158	1	2	0	0
BANAVASI	SUGAVI	MADANAKER	28	0	225	196	421	1	2	2	0
BANAVASI	SUGAVI	GONUR	24	4	364	343	707	1	1	20	0
BANAVASI	SUGAVI	HALGADDE	25	2	330	321	651	1	2	30	0
DASANKOPP	BANKANAL	KANDRAJI	52	0	191	199	390	1	1	1	0
BANAVASI	BENGLE	MARAGUNDI	32	5	671	623	1294	1	2	11	0
BANAVASI	BENGLE	BENGLE	13	1	654	664	1318	1	2	52	0
BANAVASI	BENGLE	MUGILKOPP	33	0	5	4	9	0	0	0	0
BANAVASI	BENGLE	HADALAGI	31	0	169	157	326	1	2	10	2
BANAVASI	BENGLE	KALKARDI	29	2	289	320	609	1	2	19	0
DASANKOPP	ANDAGI	ANDAGI	42	0	484	477	961	2	5	25	0
DASANKOPP	ANDAGI	KYADIGIKO	47	0	29	24	53	1	0	0	0
DASANKOPP	ANDAGI	HEBATTI	40	1	455	465	920	2	4	63	0
DASANKOPP	ANDAGI	PHARSI	44	0	53	56	109	1	1	3	0
DASANKOPP	ANDAGI	KIRWATTI	43	0	194	168	362	1	3	35	0
DASANKOPP	ANDAGI	SANTAVALL	45	0	269	269	538	1	3	32	0
DASANKOPP	ANDAGI	VADDAL	46	0	273	236	509	1	4	51	0
DASANKOPP	DASANKOPP	KUPAGADDE	51	1	583	597	1180	1	1	25	22
DASANKOPP	DASANKOPP	BELLANAKE	38	0	310	273	583	1	1	23	0
DASANKOPP	DASANKOPP	KALANGI	37	0	405	369	774	3	9	40	0
DASANKOPP	DASANKOPP	BADANGOD	35	2	1475	1555	3030	3	15	36	68
DASANKOPP	DASANKOPP	YAMAGALLI	39	0	0	0	112	1	1	0	0
DASANKOPP	DASANKOPP	KYADIKOPP	36	0	74	83	157	0	0	0	0
DASANKOPP	DASANKOPP	DHANAGANA	34	0	640	592	1232	4	3	29	0
EKKAMBI	BISALKOPP	HALLIKOPP	70	0	122	86	208	1	1	2	0
EKKAMBI	SHIVALLI	SHIVALLI	57	3	466	442	908	1	1	9	0
EKKAMBI	EKKAMBI	BOPPANALL	56	4	256	243	499	1	1	1	0
EKKAMBI	EKKAMBI	ADNALLI	55	8	366	346	712	1	1	1	0
EKKAMBI	SHIVALLI	ULLALA	59	1	195	211	406	1	1	0	0
EKKAMBI	SHIVALLI	ANAGODKOP	58	0	150	122	272	1	1	3	0
EKKAMBI	BISALKOPP	MUDEBAIL	62	0	39	44	83	1	1	0	0
EKKAMBI	BISALKOPP	VADAGERI	68	2	230	128	358	1	1	7	0
EKKAMBI	BISALKOPP	BENAGI	61	2	136	120	256	1	1	10	0
EKKAMBI	BISALKOPP	HUDELKOPP	64	0	158	152	310	2	3	13	0
EKKAMBI	BISALKOPP	BISALKOPP	60	0	340	327	667	1	2	3	0
EKKAMBI	EKKAMBI	EKKAMBI	54	2	548	567	1115	13	3	15	0
EKKAMBI	ISLUR	ISLOOR	71	3	322	303	625	1	2	32	0
EKKAMBI	ISLUR	HULADEVAN	74	2	269	254	523	1	1	2	0
EKKAMBI	ISLUR	PURA	75	0	120	98	218	1	1	0	0
EKKAMBI	ISLUR	SANNAKERI	76	0	311	258	569	1	3	22	0
EKKAMBI	BISALKOPP	HEBALLI	63	0	183	165	348	1	1	6	0
EKKAMBI	BISALKOPP	KUPPALLI	65	0	125	95	220	1	1	2	0
EKKAMBI	ISLUR	ACHANALLI	72	0	278	281	559	1	1	20	0
EKKAMBI	ISLUR	GONAGATTA	73	0	108	77	185	1	1	1	0
DASANKOPP	BANKANAL	BILUR	51	0	223	216	439	1	1	2	0
DASANKOPP	BANKANAL	UMMADI	53	0	65	52	117	1	1	0	0
EKKAMBI	BISALKOPP	KOTEKOPPA	69	0	70	51	121	1	1	0	0
EKKAMBI	BISALKOPP	HALLIKOPP	70	0	122	86	208	1	1	2	0
DASANKOPP	BANKANAL	BANKANAL	48	0	235	220	455	1	2	30	0
EKKAMBI	BISALKOPP	MALALAGOA	66	0	475	446	921	1	2	8	0
DASANKOPP	BANKANAL	MATTIHALL	49	0	92	95	187	1	1	0	0
DASANKOPP	BANKANAL	MALANJI	50	0	296	280	576	1	2	8	0

OTHERR	OTHERM	OTHERTOT	CATTLE	CATVFA	BUFFALO	GOATS	SHEEP	SHG	COP
89		89	400	2	85		150	No	No
6		6	18	0	3			No	No
37		37	173	3	33		57	No	No
226		226	518	2	140		80	No	No
213		213	730	2	267		152	No	No
460		460	874	6	526		216	No	Yes
205		205	642	5	269	138		No	No
32		32	97	2	64		68	No	No
132		132	477	3	166		20	No	No
175		175	604	5	177		132	No	Yes
109		109	160	5	111		30	No	No
140		140	308	10	96		272	No	No
8		8	64	1	9		6	No	No
35		35	133	1	5		23	No	No
35		35	155	0	37		12	No	No
28		28	70	0	22		21	No	No
28		28	109	0	31		32	No	No
34		34	96	1	42			No	Yes
75		75	113	0	74		15	No	No
37		37	69	0	16		150	No	No
24		24	27	0	15			No	No
48		48	89	0	16		120	No	No
104		104	132	0	228	114		No	No
29		29	59	1	63		9	No	No
21		21	115	1	35	38	125	No	No
57		57	198	1	45	76		No	No
161		161	348	1	67		71	No	No
132		132	212	1	69		13	No	Yes
106		106	88	0	30	25		No	No
291		291	774	1	691	327		No	No
195		195	530	1	310	120		No	No
5		5	90	1				No	No
55		55	130	1	28		24	No	No
49		49	299	1	71	25		No	No
190		190	384	2	84	1	57	No	Yes
9		9	20	0		6		No	No
312		312	385	2	40	25		No	No
69		69	64	0		12		No	No
74		74	215	2	27	15		No	No
106		106	215	1	27	15		No	No
116		116	342	3	110			No	No
138		138	283	3	38	51	1	No	No
70		70	307	2	35	35	18	No	No
146		146	267	3	52	19		No	No
643		643	989	5	188	98	4	No	Yes
			78	1					
46		46	184	1	51	74		No	No
177		177	514	1	150	59		No	No
30		30	191	1	16		10	No	No
167		167	1132	1	90		5	No	No
93		93	300	0	80		24	No	No
128		128	598	1	35		5	No	No
106		106	636	1	120		65	No	No
72		72	545	2	30	40		No	No
13		13	130	2	8			No	No
21		21	240	1	43	60		No	No
36		36	265	1	10	60		No	No
29		29	309	3	45			No	No
75		75	514	2	286	10		No	No
170		170	391	1	80	50		No	Yes
122		122	423	2	103		37	No	Yes
65		65	363	1	49	42		No	No
42		42	149	1	41			No	No
89		89	398	2	88			No	No
52		52	189	1	45			No	No
38		38	275	1	25	78		No	No
81		81	496	1	99	3	41	No	No
21		21	48	0	5			No	No
70		70	92	0	20	8	10	No	No
34		34	86	1	6	2		No	No
17		17	105	1	29	45		No	No
30		30	191	1	16		10	No	No
139		139	301	1	70			No	No
113		113	853	2	24	10		No	No
46		46	150	1	28	3		No	No
100		100	87	0	21	30		No	No

YGRP	WGRP	NGO	TEMPLE	VFCYN	DOF	MOU	MEMNOS	INTEREST
No	Yes	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
Yes	Yes	Yes	Yes	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	No	No	No	Yes	35053.00	35141.00	110.00	0
No	No	No	No	No	0	0	0	No
No	No	No	No	Yes	34655.00	35142.00	115.00	0
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	Yes	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	Yes	No	No	0	0	0	No
No	No	Yes	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	Yes	35258.00	35628.00	75.00	0
Yes	Yes	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	Yes	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	Yes	No	No	Yes	34389.00	35137.00	106.00	0
No	No	No	No	No	0	0	0	No
Yes	Yes	No	No	Yes	34694.00	35136.00	129.00	0
0	0	0	0	0	0	0	0	0
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	Yes	No	No	Yes	35268.00	35407.00	30.00	0
Yes	No	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	Yes	No	No	Yes	35046.00	35139.00	71.00	0
No	No	No	No	No	0	0	0	Yes
Yes	Yes	No	No	Yes	34111.00	34389.00	18.00	0
Yes	Yes	No	No	Yes	35268.00	35407.00	30.00	0
Yes	Yes	No	No	No	0	0	0	No
Yes	No	No	No	No	0	0	0	No
No	No	No	No	No	0	0	0	No
Yes	Yes	No	No	No	0	0	0	No

BIOPLANT	SMOKCHUL	SOLKOOK	TVA	TVA	TFA	TFA	MINOR	MINOR
1.00	8.00	0	944.30	382.16	599.33	242.55	622.43	251.90
0.00	0	0	334.30	135.29	210.55	85.21	115.75	46.84
0.00	0	0	267.88	108.41	146.63	59.34	146.63	59.34
7.00	10.00	0	1967.20	796.13	852.90	345.17	442.48	179.07
15.00	75.00	0	2001.40	809.97	984.35	398.37	293.35	118.72
33.00	22.00	0	1829.00	740.20	348.95	141.22	126.36	51.14
18.00	23.00	0	500.00	202.35	300.00	121.41	200.00	80.94
2.00	3.00	0	674.13	272.82	117.30	47.47	117.30	47.47
0.00	0	0	1043.53	422.31	362.43	146.67	362.43	146.67
6.00	12.00	0	1828.60	740.03	329.80	133.47	55.98	22.65
11.00	0	0	1022.00	413.60	80.05	32.40	80.05	32.40
6.00	0	0	1407.80	569.74	75.60	30.60	75.60	30.60
0.00	0	0	321.48	130.10	218.03	88.23	27.43	11.10
0.00	0	0	703.28	284.62	541.30	219.06	18.90	7.65
1.00	0	0	1109.65	449.08	812.35	328.76	98.55	39.88
10.00	2.00	0	902.90	365.40	725.70	293.69	37.20	15.05
0.00	0	0	719.28	291.09	559.13	226.28	499.25	202.05
7.00	0	0	459.05	185.78	348.65	141.10	166.90	67.54
20.00	4.00	0	994.65	402.53	742.90	300.65	122.05	49.39
2.00	0	0	713.48	288.74	516.43	209.00	126.08	51.02
12.00	0	0	423.00	171.19	278.90	112.87	53.75	21.75
1.00	0	0	817.43	330.81	446.30	180.62	38.83	15.71
13.00	9.00	0	2479.00	1003.25	1741.70	704.87	346.75	140.33
0.00	0	0	233.00	94.30	201.73	81.64	34.68	14.03
0.00	0	0	388.30	157.15	206.28	83.48	26.53	10.73
3.00	3.00	0	756.25	306.05	545.98	220.96	54.40	22.02
4.00	0	0	2152.15	870.98	1458.83	590.39	306.98	124.23
6.00	5.00	0	1393.00	563.75	858.90	347.60	233.65	94.56
8.00	8.00	0	1644.83	665.66	1376.60	557.11	149.60	60.54
12.00	0	0	3507.00	1419.28	2046.00	828.02	636.50	257.59
20.00	9.00	0	2298.00	930.00	1570.98	635.77	558.20	225.90
0.00	0	0	455.00	184.14	391.20	158.32	290.85	117.71
3.00	0	0	957.05	387.32	341.88	138.36	327.25	132.44
6.00	2.00	0	1387.40	561.48	838.83	339.47	267.70	108.34
3.00	11.00	0	1525.23	617.26	465.23	188.28	40.50	16.39
0.00	0	0	1387.00	561.54	692.18	280.12	104.50	42.29
7.00	5.00	0	1433.80	580.26	553.00	223.80	422.68	171.06
0.00	0	0	387.40	156.78	360.40	145.85	55.20	22.34
9.00	5.00	0	868.20	351.36	350.55	141.87	192.55	77.93
12.00	2.00	0	984.33	398.36	442.48	179.07	326.28	132.04
4.00	5.00	0	874.25	353.81	285.13	115.39	285.13	115.39
2.00	0	0	0.00	0.00	0.00	0.00	148.90	60.26
5.00	106.00	0	1025.00	414.98	0.00	0.00	282.20	114.21
2.00	0	0	653.20	264.35	216.88	87.77	32.03	12.96
10.00	110.00	0	2369.10	958.77	512.30	207.33	190.65	77.16
0.00	0	0	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0	0	3522.05	1425.37	862.25	348.95	89.58	36.25
1.00	0	0	832.30	336.83	889.55	360.00	91.03	36.84
0.00	3.00	0	521.15	210.91	424.40	171.75	123.80	50.10
16.00	12.00	0	3604.05	1458.56	3199.63	1294.89	938.23	379.70
34.00	7.00	0	1957.93	792.37	1720.93	696.46	95.53	38.66
32.00	15.00	0	3019.75	1222.09	2688.28	1087.95	374.75	151.66
11.00	15.00	0	1568.75	634.87	1204.90	487.62	154.78	62.64
14.00	4.00	0	1055.25	427.06	787.05	318.52	113.78	46.04
2.00	6.00	0	305.68	123.71	202.53	81.96	15.08	6.10
0.00	0	0	0.00	0.00	0.00	0.00	149.03	60.31
0.00	0	0	844.00	341.57	747.53	302.52	156.03	63.14
2.00	15.00	0	429.28	173.73	257.13	104.06	80.15	32.44
30.00	30.00	0	1137.00	460.14	809.00	327.40	160.68	65.03
6.00	25.00	0	218.50	88.43	999.83	404.63	144.30	58.40
10.00	15.00	0	1429.00	578.32	650.63	263.31	25.60	10.36
7.00	10.00	0	1269.73	513.86	1004.95	406.70	97.70	39.54
11.00	6.00	0	749.68	303.39	368.98	149.32	75.05	30.37
10.00	14.00	0	1150.68	465.68	519.65	210.30	181.20	73.33
6.00	1.00	0	943.58	381.86	690.93	279.62	112.50	45.53
8.00	0	0	737.60	298.51	509.75	206.30	54.58	22.09
5.00	15.00	0	1400.00	566.58	1080.00	437.08	66.63	26.96
2.00	10.00	0	475.00	192.23	399.85	161.82	23.93	9.68
10.00	71.00	0	1277.65	517.07	963.80	390.05	210.50	85.19
0.00	6.00	0	441.58	178.71	314.90	127.44	166.00	67.18
9.00	16.00	0	402.03	162.70	266.03	107.66	46.00	18.62
0.00	3.00	0	521.15	210.91	424.40	171.75	123.80	50.10
3.00	0	0	1025.00	414.82	652.48	264.06	60.68	24.56
5.00	15.00	0	1696.63	686.62	1003.53	406.13	109.95	44.50
0.00	4.00	0	724.10	293.04	534.98	216.50	77.98	31.56
6.00	0	0	1376.43	557.04	617.63	249.95	36.25	14.67

PROPER	PROPER	BETTA	BETTA	TOTAL	TOTAL	CHKPOST	DEPOTS	BEATOFF
0	0.00	0	0.00	622.43	251.90	0	0	0
94.80	38.37	0	0.00	210.55	85.21	0	0	0
0	0.00	0	0.00	146.63	59.34	0	0	0
152.20	61.60	112.80	45.65	707.48	286.32	0	0	0
691.00	279.65	0	0.00	984.35	398.37	0	0	0
222.05	89.86	0	0.00	348.41	141.00	0	1.00	1.00
200.00	80.94	200.00	80.94	600.00	242.82	0	0	0
0	0.00	0	0.00	117.30	47.47	0	0	0
0	0.00	0	0.00	362.43	146.67	0	0	0
273.83	110.82	0	0.00	329.80	133.47	0	0	0
0	0.00	0	0.00	80.05	32.40	0	0	0
0	0.00	0	0.00	75.60	30.60	0	0	0
190.60	77.14	0	0.00	218.03	88.23	0	0	0
522.40	211.42	0	0.00	541.30	219.06	0	0	0
760.28	307.68	7.88	3.19	866.70	350.75	0	0	0
495.40	200.49	193.10	78.15	725.70	293.69	0	0	0
59.88	24.23	0	0.00	559.13	226.28	0	0	0
173.43	70.19	0	0.00	340.33	137.73	0	0	0
479.53	194.06	141.33	57.19	742.90	300.65	0	0	0
315.93	127.85	74.43	30.12	516.43	209.00	0	0	0
95.65	38.71	129.50	52.41	278.90	112.87	0	0	0
407.48	164.91	0	0.00	446.30	180.62	0	0	0
1055.48	427.15	339.48	137.39	1741.70	704.87	0	0	1.00
167.05	67.61	0	0.00	201.73	81.64	0	0	0
179.75	72.74	0	0.00	206.28	83.48	0	0	0
481.43	194.83	10.15	4.11	545.98	220.96	0	0	0
1151.85	466.15	0	0.00	1458.83	590.39	0	0	0
543.58	219.98	81.68	33.05	858.90	347.60	0	0	0
1218.00	492.92	9.00	3.64	1376.60	557.11	0	0	0
1236.50	500.41	148.25	60.00	2021.25	818.00	0	0	0
314.30	127.20	689.35	278.98	1561.85	632.08	0	0	0
100.35	40.61	0	0.00	391.20	158.32	0	0	0
0	0.00	14.63	5.92	341.88	138.36	0	0	0
574.38	232.45	0	0.00	842.08	340.79	0	0	0
424.73	171.89	0	0.00	465.23	188.28	0	0	0
587.68	237.83	0	0.00	692.18	280.12	0	0	0
40.38	16.34	90.20	36.50	553.25	223.90	0	0	0
305.20	123.51	0	0.00	360.40	145.85	0	0	0
137.95	55.83	20.05	8.11	350.55	141.87	0	0	0
79.35	32.11	36.85	14.91	442.48	179.07	0	0	0
0	0.00	0	0.00	285.13	115.39	0	0	0
1043.13	422.15	0	0.00	1192.03	482.41	0	0	0
9.35	3.78	0	0.00	291.55	117.99	0	0	0
153.35	62.06	31.50	12.75	216.88	87.77	0	0	0
325.65	131.79	0	0.00	516.30	208.95	1.00	0	1.00
0	0.00	0	0.00	0.00	0.00	0	0	0
772.68	312.70	0	0.00	862.25	348.95	0	0	0
767.10	310.45	31.43	12.72	889.55	360.00	0	0	0
88.40	35.78	212.20	85.88	424.40	171.75	0	0	0
2002.65	810.47	258.75	104.72	3199.63	1294.89	0	0	0
1336.13	540.73	289.28	117.07	1720.93	696.46	0	0	0
1795.38	726.59	518.15	209.70	2688.28	1087.95	0	0	0
801.58	324.40	248.55	100.59	1204.90	487.62	0	0	0
565.08	228.69	108.20	43.79	787.05	318.52	0	0	0
187.45	75.86	0	0.00	202.53	81.96	0	0	0
310.43	125.63	0	0.00	459.45	185.94	0	0	0
552.88	223.75	38.63	15.63	747.53	302.52	0	0	0
152.80	61.84	24.18	9.78	257.13	104.06	0	0	0
16.75	6.78	631.58	255.60	809.00	327.40	0	0	0
802.88	324.92	52.50	21.25	999.68	404.57	1.00	0	4.00
294.88	119.34	260.15	105.28	580.63	234.98	0	0	1.00
799.28	323.47	107.78	43.62	1004.75	406.62	0	0	0
172.88	69.96	121.13	49.02	369.05	149.35	0	0	0
241.48	97.72	96.98	39.25	519.65	210.30	0	0	0
576.85	233.45	1.58	0.64	690.93	279.62	0	0	0
423.68	171.46	31.50	12.75	509.75	206.30	0	0	0
1006.68	407.40	6.70	2.71	1080.00	437.08	0	0	0
376.43	152.34	0	0.00	400.35	162.02	0	0	0
753.30	304.86	0	0.00	963.80	390.05	0	0	0
148.90	60.26	0	0.00	314.90	127.44	0	0	0
220.03	89.04	0	0.00	266.03	107.66	0	0	0
88.40	35.78	212.20	85.88	424.40	171.75	0	0	0
520.25	210.55	71.55	28.96	652.48	264.06	0	0	0
832.48	336.90	61.10	24.73	1003.53	406.13	0	0	0
457.05	184.97	0	0.00	535.03	216.52	0	0	0
581.38	235.28	0	0.00	617.63	249.95	0	0	0

SECOFF	NURSERY	WTOWER	FIREINCI	Y9293	Y9394	Y9495	Y9596	Y9697
0	0	0	Problem	3.00	5.00	1.00	4.00	3.00
0	0	0	Problem	6.00	2.00	2.00	3.00	9.00
0	0	0	Problem	2.00	1.00	1.00	0.00	0.00
0	0	0	Problem	0.00	6.00	1.00	3.00	3.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
1.00	1.00	0.00	Problem	0.00	6.00	1.00	3.00	3.00
0	0	0	Problem	6.00	5.00	4.00	3.00	10.00
0	0	0	Problem	0.00	0.00	0.00	1.00	0.00
0	0	0	Problem	0.00	0.00	0.00	0.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	0	No Proble	3.00	5.00	1.00	4.00	3.00
0	0	0	Problem	2.00	4.00	0.00	1.00	4.00
0	0	0	Problem	2.00	0.00	0.00	0.00	2.00
0	0	0	Problem	2.00	0.00	7.00	8.00	5.00
0	0	0	Problem	1.00	0.00	0.00	0.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	0	Problem	1.00	2.00	0.00	0.00	0.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	1.00	Problem	0.00	0.00	2.00	0.00	1.00
0	0	0	Problem	3.00	2.00	0.00	1.00	5.00
0	0	0	No Proble	0.00	2.00	0.00	2.00	1.00
0	0	0	Problem	0.00	0.00	1.00	0.00	2.00
0	0	0	Problem	3.00	0.00	4.00	2.00	3.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	0	Problem	0.00	4.00	0.00	0.00	0.00
0	0	0	Problem	5.00	10.00	1.00	1.00	2.00
0	0	0	Problem	7.00	7.00	1.00	1.00	3.00
0	0	0	Problem	0.00	4.00	3.00	1.00	1.00
0	0	0	Problem	0.00	1.00	1.00	1.00	3.00
0	0	0	Problem	1.00	0.00	2.00	0.00	1.00
0	0	0	No Proble	0.00	0.00	0.00	1.00	1.00
0	0	0	Problem	1.00	1.00	0.00	1.00	1.00
0	0	0	Problem	2.00	7.00	4.00	5.00	4.00
0	0	0	Problem	5.00	7.00	4.00	5.00	4.00
0	0	0	Problem	0.00	1.00	0.00	2.00	0.00
0	0	0	Problem	0.00	1.00	0.00	0.00	2.00
0	0	0	Problem	0.00	0.00	0.00	1.00	2.00
0	0	0	Problem	2.00	0.00	0.00	1.00	1.00
0	0	0	Problem	0.00	0.00	0.00	1.00	3.00
0	0	0	Problem	1.00	1.00	1.00	1.00	0.00
0	0	0	Problem	1.00	1.00	1.00	1.00	1.00
0	0	0	Problem	2.00	2.00	0.00	4.00	2.00
0	0	0	Problem	0.00	1.00	2.00	2.00	3.00
0	0	0	Problem	1.00	0.00	2.00	1.00	0.00
1.00	0	0	Problem	3.00	2.00	3.00	3.00	3.00
0	0	0	0	1.00	2.00	3.00	1.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	0	Problem	4.00	0.00	0.00	0.00	0.00
0	0	0	Problem	6.00	5.00	9.00	4.00	6.00
0	0	0	Problem	4.00	11.00	3.00	7.00	2.00
0	0	0	Problem	11.00	17.00	1.00	6.00	2.00
0	0	0	Problem	3.00	4.00	1.00	2.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	0.00
0	0	0	Problem	6.00	13.00	3.00	6.00	6.00
0	0	0	Problem	2.00	2.00	1.00	5.00	6.00
0	0	0	Problem	0.00	11.00	3.00	11.00	4.00
0	0	0	Problem	5.00	3.00	0.00	2.00	3.00
0	0	0	Problem	0.00	0.00	0.00	0.00	1.00
0	0	0	Problem	1.00	1.00	1.00	1.00	0.00
1.00	0	0	Problem	6.00	5.00	0.00	0.00	0.00
0	0	0	Problem	1.00	3.00	1.00	0.00	0.00
0	0	0	Problem	1.00	2.00	1.00	1.00	1.00
0	0	0	Problem	5.00	6.00	2.00	1.00	0.00
0	0	0	Problem	3.00	3.00	1.00	1.00	3.00
0	0	0	Problem	0.00	0.00	2.00	1.00	1.00
0	0	0	Problem	1.00	4.00	1.00	3.00	1.00
0	0	0	Problem	2.00	0.00	0.00	0.00	0.00
0	0	0	Problem	1.00	3.00	0.00	0.00	0.00
0	0	0	Problem	0.00	0.00	1.00	0.00	0.00
0	0	0	Problem	5.00	3.00	5.00	5.00	2.00
0	0	0	Problem	0.00	0.00	2.00	0.00	0.00
0	0	0	Problem	6.00	5.00	9.00	4.00	6.00
0	0	0	Problem	0.00	0.00	0.00	0.00	1.00
0	0	0	Problem	0.00	2.00	0.00	1.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	1.00
0	0	0	Problem	0.00	0.00	0.00	0.00	2.00

TOTOFFN	ENCH_AREA	ENCH_AREA	HOUSEHOLDS	KFDCAREA	KFDCAREA	KFDCVFSN	DISFAREA	DISFAREA	DISFVFSN
16	5.00	2.02	3.00	0	0	0	0	0.00	0
22	0.75	0.30	1.00	0	0	0	0	0.00	0
4	20.00	8.09	7.00	0	0	0	0	0.00	0
13	25.00	10.12	22.00	0	0	0	0	0.00	0
0	45.00	18.21	19.00	0	0	0	0.25	0.10	277.00
13	25.00	10.12	22.00	0	0	0	1.00	0.41	166.00
28	50.00	20.24	32.00	0.00	0	0	28.60	11.57	174.00
1	7.50	3.04	4.00	0	0	0	0	0.00	0
1	22.50	9.11	13.00	0	0	0	0	0.00	0
0	32.50	13.15	20.00	0	0	0	0	0.00	0
16	5.00	2.02	3.00	0	0	0	0	0	0
11	10.00	4.05	5.00	0	0	0	0	0.00	0
4	0.00	0.00	0.00	0	0	0	0	0.00	0
22	30.00	12.14	8.00	0	0	0	2.00	0.81	18.00
2	20.00	8.09	10.00	0	0	0	1.00	0.41	8A
0	35.00	14.16	9.00	0	0	0	22.38	9.06	28A,32,38
3	25.00	10.12	5.00	0	0	0	1.00	0.41	173.00
0	26.00	10.52	6.00	0	0	0	7.80	3.16	23.00
3	25.00	10.12	5.00	0	0	0	21.43	8.67	22,23,24
11	30.00	12.14	9.00	0	0	0	3.03	1.22	7.00
5	0.00	0.00	0.00	0	0	0	0	0.00	0
3	9.00	3.64	2.00	0	0	0	0	0.00	0
12	36.00	14.57	8.00	0	0	0	85.58	34.63	103.00
0	60.00	24.28	14.00	0	0	0	0	0.00	0
4	16.00	6.48	4.00	0	0	0	0	0.00	0
19	12.00	4.86	3.00	0	0	0	0	0.00	0
19	91.00	36.83	16.00	0	0	0	16.58	6.71	6,11,53
9	25.00	10.12	5.00	0	0	0	8.15	3.30	37.00
6	80.00	32.38	24.00	0	0	0	0	0.00	0
4	150.00	60.71	118.00	8.48	3.43	12.00	6.33	2.56	13.00
2	50.00	20.24	22.00	0	0	0	8.85	3.58	44.00
4	5.00	2.02	4.00	0	0	0	0	0.00	0
22	10.00	4.05	9.00	0	0	0	19.65	7.95	33,39
25	150.00	60.71	62.00	0	0	0	10.08	4.08	43.00
3	50.00	20.24	15.00	0	0	0	0	0	0
3	8.00	3.24	4.00	0	0	0	0	0.00	0
3	150.00	60.71	60.00	40.38	16.34	213.00	120.33	48.70	4-8,206..
4	40.00	16.19	10.00	0	0	0	0	0.00	0
4	87.00	35.21	37.00	68.23	27.61	82.00	68.55	27.74	34,35..81
4	100.00	40.47	22.00	79.35	32.11	27.00	18.23	7.38	52,55
5	175.00	70.82	58.00	235.00	95.11	84.00	65.95	26.69	4,33,56,6
10	50.00	20.24	15.00	168.00	67.99	54141.00	10.08	4.08	59A,59B
8	50.00	20.24	15.00	90.00	36.42	6.00	0	0.00	0
4	30.00	12.14	15.00	0	0	0	0	0.00	0
14	32.00	12.95	28.00	0	0	0	7.58	3.07	186187.00
8	0.00	0.00	0.00	0	0	0	0	0	0
0	75.00	30.35	20.00	497.00	201.14	15,65	0	0.00	0
4	150.00	60.71	55.00	24.00	9.71	45130.00	21.28	8.61	44133.00
30	30.00	12.14	18.00	0	0	0	31.78	12.86	15,16,17
27	201.30	81.47	116.00	0	0	0	0	0.00	0
37	130.00	52.61	62.00	0	0	0	0	0.00	0
11	153.63	62.17	32.00	0	0	0	0	0	0
0	57.00	23.07	53.00	0	0	0	0	0.00	0
34	7.70	3.12	20.00	0	0	0	0	0	0
16	13.65	5.52	13.00	0	0	0	0	0.00	0
29	21.00	8.50	16.00	0	0	0	0	0.00	0
13	45.00	18.21	29.00	0	0	0	0	0.00	0
1	25.00	10.12	10.00	0	0	0	0	0.00	0
4	0.00	0.00	0.00	0	0	0	2.00	0.81	35.00
11	38.35	15.52	114.00	0	0	0	0	0.00	0
5	25.00	10.12	45.00	0	0	0	0	0.00	0
6	15.00	6.07	30.00	0	0	0	0	0.00	0
14	32.50	13.15	23.00	0	0	0	0	0.00	0
11	40.00	16.19	49.00	0	0	0	0	0.00	0
4	37.55	15.20	19.00	0	0	0	18.28	7.40	25,27
10	20.00	8.09	19.00	0	0	0	0	0.00	0
2	30.00	12.14	32.00	0	0	0	0	0	0
4	15.00	6.07	6.00	0	0	0	0	0.00	0
1	100.00	40.47	40.00	7.85	3.18	10.00	3.35	1.36	26.00
20	15.00	6.07	6.00	0	0	0	0	0.00	0
2	22.00	8.90	18.00	0	0	0	5.98	2.42	10.00
30	30.00	12.14	18.00	0	0	0	31.78	12.86	15,16,17
1	100.00	40.47	38.00	0	0	0	0	0.00	0
4	84.38	34.15	48.00	0	0	0	28.28	11.44	78, 102
1	60.00	24.28	20.00	3.63	1.47	5.00	0	0.00	0
2	65.00	26.31	20.00	0	0	0	0	0.00	0

DISFAREA	DISFAREA	DISFVFSN	MINESAREA	MINESAREA	MINESVFSN	SCSTLEASEA	SCSTLEASEA	SCSTLEASEV	GINI	TOTOFF
0	0.00	0	0	0	0	0	0	0	0.14	16
0	0.00	0	0	0	0	0	0	0	0.23	22
0	0.00	0	0	0	0	0	0	0	0.18	4
0	0.00	0	0	0	0	0	0	0	0.17	13
0.25	0.10	277.00	0	0	0	0	0	0	0.19	0
1.00	0.41	166.00	0	0	0	0	0	0	0.13	13
28.60	11.57	174.00	9.00	3.64	161.00	8.90	3.60	175.00	0.21	28
0	0.00	0	0	0	0	0	0	0	0.23	1
0	0.00	0	0	0	0	0	0	0	0.21	1
0	0.00	0	1.00	0.41	108.00	0	0	0	0.18	0
0	0	0	0	0	0	0	0	0	0.19	16
0	0.00	0	0	0	0	0	0	0	0.18	11
0	0.00	0	0	0	0	0	0	0	0.49	4
2.00	0.81	18.00	0	0	0	0	0	0	0.48	22
1.00	0.41	8A	0	0	0	0	0	0	0.48	2
22.38	9.06	28A,32,38	0	0	0	0	0	0	0.61	0
1.00	0.41	173.00	0.25	0.10	195.00	0	0	0	0.48	3
7.80	3.16	23.00	0	0	0	0	0	0	0.45	0
21.43	8.67	22,23,24	0	0	0	0	0	0	0.39	3
3.03	1.22	7.00	0	0	0	0	0	0	0.46	11
0	0.00	0	0	0	0	0	0	0	0.71	5
0	0.00	0	0	0	0	0	0	0	0.39	3
85.58	34.63	103.00	0	0	0	0	0	0	0.17	12
0	0.00	0	0	0	0	0	0	0	0.03	0
0	0.00	0	0	0	0	0	0	0	0.16	4
0	0.00	0	0	0	0	0	0	0	0.22	19
16.58	6.71	6,11,53	0	0	0	0	0	0	0.16	19
8.15	3.30	37.00	0	0	0	0	0	0	0.19	9
0	0.00	0	0	0	0	0	0	0	0.13	6
6.33	2.56	13.00	3.58	1.45	160.00	6.98	2.82	161.00	0.18	4
8.85	3.58	44.00	2.00	0.81	268.00	0	0	0	0.13	2
0	0.00	0	0	0	0	0	0	0	0.10	4
19.65	7.95	33,39	0	0	0	0	0	0	0.19	22
10.08	4.08	43.00	0	0	0	0	0	0	0.31	25
0	0	0	0	0	0	0	0	0	0.12	3
0	0.00	0	0	0	0	0	0	0	0.18	3
120.33	48.70	4-8,206..	0	0	0	0	0	0	0.32	3
0	0.00	0	0	0	0	0	0	0	0.12	4
68.55	27.74	34,35..81	0	0	0	0	0	0	0.20	4
18.23	7.38	52,55	0	0	0	0	0	0	0.18	4
65.95	26.69	4,33,56,6	0	0	0	0	0	0	0.14	5
10.08	4.08	59A,59B	0	0	0	0	0	0	0.29	10
0	0.00	0	0	0	0	0	0	0	0.56	8
0	0.00	0	0	0	0	0	0	0	0.13	4
7.58	3.07	186187.00	0	0	0	0	0	0	0.27	14
0	0	0	0	0	0	0	0	0	0.00	8
0	0.00	0	0	0	0	0	0	0	0.20	0
21.28	8.61	44133.00	0	0	0	0	0	0	0.24	4
31.78	12.86	15,16,17	0	0	0	0	0	0	0.15	30
0	0.00	0	0	0	0	0	0	0	0.07	27
0	0.00	0	0	0	0	0	0	0	0.10	37
0	0	0	0	0	0	0	0	0	0.07	11
0	0.00	0	0	0	0	0	0	0	0.13	0
0	0	0	0	0	0	0	0	0	0.15	34
0	0.00	0	0	0	0	0	0	0	0.27	16
0	0.00	0	0	0	0	0	0	0	0.10	29
0	0.00	0	4.98	2.01	0	0	0	0	0.25	13
0	0.00	0	0	0	0	0	0	0	0.09	1
2.00	0.81	35.00	0	0	0	0	0	0	0.22	4
0	0.00	0	0	0	0	0	0	0	0.06	11
0	0.00	0	0	0	0	0	0	0	0.20	5
0	0.00	0	0	0	0	0	0	0	0.14	6
0	0.00	0	0	0	0	0	0	0	0.15	14
0	0.00	0	0	0	0	0	0	0	0.17	11
18.28	7.40	25,27	0	0	0	0	0	0	0.15	4
0	0.00	0	0	0	0	0	0	0	0.21	10
0	0	0	0	0	0	0	0	0	0.14	2
0	0.00	0	0	0	0	0	0	0	0.07	4
3.35	1.36	26.00	0	0	0	0	0	0	0.20	1
0	0.00	0	0	0	0	0	0	0	0.16	20
5.98	2.42	10.00	0	0	0	0	0	0	0.23	2
31.78	12.86	15,16,17	0	0	0	0	0	0	0.15	30
0	0.00	0	0	0	0	0	0	0	0.23	1
28.28	11.44	78, 102	0	0	0	0	0	0	0.20	4
0	0.00	0	0	0	0	0	0	0	0.17	1
0	0.00	0	0.38	0.15	54.00	0	0	0	0.25	2