A Geo-Information System Approach for Strengthening Conservation Measures in Protected Area with Reference to Forest Fire

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Abstract

Innumerable forest fire spread models exist for taking decision towards effective fire management using the spatio-temporal database system. Most fire models operate at various scales using different algorithms for fire prediction and produce value/ maps denoting fire-frequency, fire-severity, fire-spread rate, fire-burn pattern or fire-risk. Prime variables considered in modelling are environmental variables and very less focus is on the real causative factors which initiate/ ignite fire in an area. It has been observed that the majority of the forest fires are caused as a result of biotic factors.

The purpose of this study was to develop a geo-information system approach for tackling forest fire in Mudumalai Wildlife Sanctuary, Tamilnadu. In this study the main objective was to develop forest fire likelihood model integrating GIS and knowledge based approach for predicting fire-sensitive ignition areas considering major causative and anti-causative factors and suggest appropriate management strategy for strengthening conservation measures in the Protected Area (PA). In this modelling, various causative factors were identified and it was found that wildlife dependent (antler collection and poaching) contributed significantly to the fire occurrence followed by management dependent (uncontrolled tourism and grazing) with very less influence of demographic factors. Similarly, anti-causative factor (stationing of anti-poaching/ fire camps) was considered quite significant.

The likelihood model so developed envisaging various factors and habitat (flammability) accounted for different scenarios as a result pair-wise comparison on ordinal scale in knowledge matrix. The inferential statistics computed indicated towards the robustness of the model and its insensitivity to moderate changes. The area value evaluation model formulated with ecological, economic and social values was found extremely significant in terms of management intervention and regular fire incidences. Prioritization of the mitigation strategy provided for appropriate location of the various management interventions vis-à-vis likelihood model with area value and indicated further reduction in the fire likelihood. The model forms a good analysis tool for resource managers. A Graphic User Interface (GUI) so developed with the prototype allows the user to easily search, analyze and edit the information necessary to execute each simulation.

It makes possible for this forest fire likelihood model to predict and to prevent forest fire in effective and scientific manner because it can assume exact forest fire likelihood in real time and present in proper time.

Keywords: causative factor, anti-causative factor, likelihood, area value, mitigation, customization

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1. Introduction

This chapter provides the background & justification undertaking the study. It spells out the most critical disturbance viz. 'forest fire', which needs to be tackled adopting geo-information system approach. It gives an overview of the forest fire scenario – nationally and internationally with its impact and significance in context of Protected Area (PA) conservation. It provides an understanding of the important terms used in relation to the wild fires. The chapter spells out the research problem and the driving force in undertaking this study. It details the various objectives of the research and the necessary questions for addressing. The conceptual model has been visualized which forms the basis for the research design. The research design incorporates along with fieldwork both phases of pre- & post-fieldwork. Finally, the chapter provides the structure of the thesis.

1.1. Background & Justification

Today's world is engulfed with numerous problems and the biological resources are facing enormous pressures from the human civilization, thereby causing serious reduction in biological diversity. 'Biological diversity' or 'biodiversity' is the variety and variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic systems and the ecological complexes in which they occur; this includes diversity within species; between species; and of ecosystems (United Nations Conference on Environment and Development, 1992). Biological resources provide the basis for human sustenance and life on this earth. At the same time, biological diversity brings benefits to the community and therefore, it is of utmost importance to strengthen and maintain the diversity of biological resources at local, regional, national and international level. The increased concern for preservation of biodiversity increases the complexity of the forest management planning and new tools are needed in order to accomplish planning (Erik Næsset, 1997). Conservation requirements are based on the natural resource values of an area, which are the biological communities and the related habitat parameters coupled with minimum human influence. For conserving biological diversity including human uses and ecological relationships, various kinds of information and knowledge is required. Recent advances in database and scientific knowledge makes such information easily accessible than ever. Developing and using information in a scientific manner is therefore an essential part of conservation at all levels – from local to the global community. It seems obvious that increasing knowledge about the kind and variety of organisms, their associated habitats and relationship to humans forms the basis for strengthening the conservation measures.

India has an extremely rich repository of flora and fauna. The rapid decline of wildlife and threat to its habitat has been a cause of concern. The State has constituted areas of adequate ecological, faunal, floral, geomorphological or natural significance as 'Protected Areas' (PA) for the purpose of protecting, propagating or developing wildlife or its environment (Wildlife Protection Act, 1972). Establishment and management of protected areas together with conservation, sustainable use and restoration initiatives are central to Article 8 on "In-situ Conservation" of the Convention on Biological Diversity.

In-situ Conservation is the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings.

The Convention on Biological Diversity (CBD) defines protected areas as:

"a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives."

Whereas, International Union of Conservation of Nature (IUCN) defines protected areas as:

"areas of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means."

Protected areas are extremely significant in the conservation of the country's natural and cultural resources. Their importance ranges from the protection of natural habitats and associated flora and fauna, to the maintenance of environmental stability of adjoining regions. They can provide opportunities and multiple values, which have ecological, economic, educational, recreational and social connotations. However, PA's in the country are exposed to various conservation threats. The most critical disturbance happens to be the forest fire.

Forest fires, also called wildfire or wild land fire, take place in uninhabited or uncultivated areas. Archaeological indication of the use of fire by the first human civilization dates back to Palaeolithic era (WWF Report, 2003). Initially, fire offered pre-historic man security against wild animals and subsequently has been used for clearing land and driving game animals (Alexander, 1993). In the recent past, fire has also been used for improving wildlife habitat and grassland for livestock (Agee, 1993). Thus from pre-history to modern age, fire has played a critical role in environmental change. According to E.P. Odum, famous ecologist, "Fire is not always bad for man's interests and if we cannot learn to handle this relatively simple environmental factor in our own best interest, we have no business attempting to control rainfall or other vastly more complex matters" (Odum, 1971). Occurrence of forest fire is on the increase every year due to various reasons, which imposes severe threat on biodiversity of any country. Almost 6 million km^2 of forests have been lost in less than 200 years due to wildfires (Dimopoulou & Giannikos 2002). Forest fires are considered a potential hazard having physical, biological, ecological and environmental consequences. Fire disturbance has important ecological effects in many forest landscapes (Jian Yang, Hong S. He and Eric J. Gustafson December 2004). Forest fire results in partial or complete destruction of vegetation cover which modifies the radiation balance by increasing the surface albedo, water runoff and raising the soil erosion (Mulyanto Darmawan, 2001).

1.1.1. Forest Fires – Global scenario

As per the Global Forest Fire Assessment Report of 1999 – 2000 (Forestry Resource Assessment Programme, FAO, 2000), the 1980's and 1990's experienced high inter-annual regional and national variability of fire occurrence and fire impacts. Both decades were marked with the extreme climatic oscillations affecting area burned and impact of fire (El Niño episodes in 1982-1983 and 1997-1998). Most of the regions in tropical Asia, Africa, North & South America and Oceania experienced extreme wildfire situations. The Report mentions increased fire situations in the equatorial forest regions of Southeast Asia and South America and extremely dry years in the northern temperate/boreal forest zone. In 1987, wildfire affected Central-Eastern Asia most severely and the Far East of Russia with 1998 drought. Statistical evidence from National Forests in the western United States also show an increasing trend in the area burned from the mid-1980s as compared to the earlier part of the 20th century (Figure 1.1).

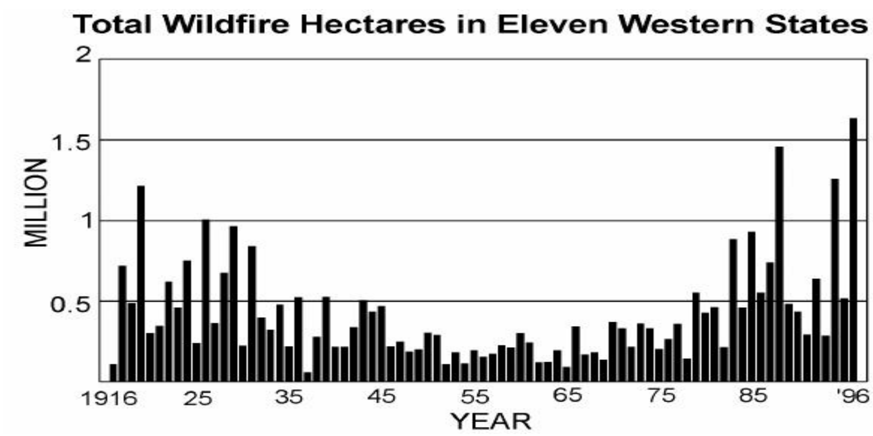


Figure 1. 1: Trend in wildfire in the eleven western states of US between 1916- 1996

(Source: Global Forest Fire Assessment Report of 1999 – 2000, FRA Programme, FAO, 2000)

Differing fire response strategies and unnatural fuel accumulations in the U.S. help to explain some of these increases in area burned. Data from Europe & North America suggests similar trend in the number of fire occurrences and area burnt in the two continents, however, linear relationship between the two is not apparent (Figures 1.2 & 1.3).

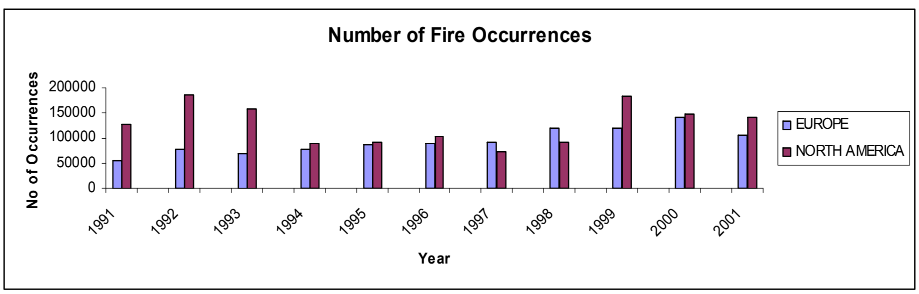


Figure 1. 2: Graph illustrating the number of fire occurrences in Europe & N. America from 1991-2001

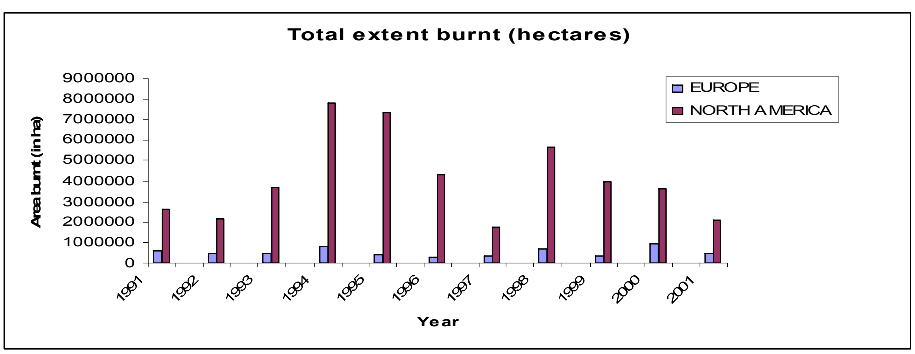


Figure 1. 3: Graph illustrating the total extent burnt in Europe & North America from 1991-2001

According to the FRA Report (FAO, 2000), some areas have suffered more fires due to increasing land-use intensity. Other forest regions have become more susceptible to increased fires because of long-term fire exclusion. Due to repeated fires, large areas of degraded forests and other wooded lands have been converted to grasslands and shrublands. These are prone to burn much more frequently, inhibiting back the normal tree succession.

1.1.2. Forest Fires – Indian scenario

The forest cover in the country is 678,333 km^2 and constitutes 20.64% of its geographic area. Of this, the very dense forest comprises 1.56%, moderately dense constitutes 10.32% and open forest constitutes 8.76% (Forest Survey of India, 2003). India has a variety of climate zones, including broad zones as tropical region in the south, northwestern deserts, Himalayan mountains, and the wet region of the northeast. Forests are widely distributed in the country with a variety of biomes and biological communities. The forest vegetation in the country varies from tropical evergreen forests in the South-Western Coast and in the Northeast to alpine forests in the Northern Himalayas. In between the two extremes, there are semi-evergreen, deciduous, sub-tropical broad-leaved hill & pine forests and subtropical montane temperate forests. With increasing livestock and population pressures, the forest cover of the country is deteriorating very fast. Along with various factors, forest fires happen to be a major cause of degradation of Indian forests. According to a Forest Survey of India, about 50 percent of forest areas in the country are fire prone (Table: 1.1).

State/ District	Forest Area	Sample Plots	Extent of fire incidents						Total
			Very Heavy	Heavy	Frequent	Occasional	No Fire	Unrec	
Andhra Pradesh	14826.71	2037	60.58	5.75	521.99	3335.27	10016.34	886.78	14826.71
Assam	15427.88	2482	70.91	0	590.25	4551.13	10176.68	38.01	15427.88
Bihar	5317.01	296	57.718	0	452.6223	3330.7426	1505.927	0	5317.01
Himachal Pradesh	10269.40	4878	163.7	0	671.45	3811.38	5054.92	567.98	10269.40
Jammu & Kashmir	3331.75	428	7.5	0	60.98	1089.58	2088.05	85.64	3331.75
Haryana & Punjab	1180.72	45	0	0	41.54	332.48	807.7	0	1180.72
Karnataka	13223.30	1780	59.71	30.33	470.64	3342.94	9309.79	9.89	13223.30
Manipur	15154.00	1880	0	151.54	454.62	5758.52	8789.32	0	15154.00
Madhya Pradesh	1962591	1947	136.53	23.07	1838.83	10644.29	6983.19	0	19625.91
Maharashtra	8165.54	1355	0	0	186.83	4222.57	3756.94	0	8165.54
Meghalaya	9905.00	1659	26.75	0	269.12	3347.25	5230.91	1031.6	9905.66
Nagaland	14954.91	1128	0	0	1084.231	12038.703	1831.976	0	14954.91
Orissa	20143.38	2972	204.42	78.5	923.19	11345.345	5258.182	333.52	20143.38
Rajasthan	20178.79	2446	71.39	0	99.03	4348.12	14763.26	896.99	20178.79
Sikkim	1707.77	401	47.12	0	18.14	544.84	1097.67	0	1707.77
Tripura	6445.36	555	34.59	0	361.75	5293.65	755.37	0	6445.36
Uttar Pradesh	23164.09	2825	871.43	0	2092.51	11124.1	907605	0	23164.09
West Bengal	5764.81	1471	4.77397	0	656.4338	1356.5246	3444.318	302.76	5764.81
Dadra & Nagar	186.49	62	0	0	0	180.8953	5.5947	0	186.49
Grand Total	**208973.48**	**307.47**	**1817.122**	**289.19**	**10794.16**	**89998.3305**	**101952.188**	**4154.07**	**208973.48**
Percentage			**0.87**	**0.14**	**5.16**	**43.06**	**48.79**	**1.99**	**100.00**

Table 1. 1: Countrywide data on extent of fire incidents by Forest Survey of India (1995)

Nearly 6 percent of the forests are susceptible to severe fire damage. As per the assessment of the Forest Protection Division of the Ministry of Environment and Forests, Government of India, wildfires, annually in India, affect about 3.73 million hectares of forests (Bahuguna & Singh, 2000)

The vulnerability of the Indian forests to fire varies from place to place depending upon the type of vegetation and the climate. The coniferous forest in the Himalayan region comprising of pines (*Pinus roxburgi & Pinus wallichiana),* fir (*Abies pindrow*), spruce (*Picea smithiana*), deodar (*Cedrus deodara)* etc are very prone to fire. The other parts of the country are dominated by deciduous forests, which are also damaged by fire (Table 1.2) (Bahuguna & Singh, 2000).

	Type of Forests	**Fire frequent (%)**	**Fire Occasional (%)**
1	Coniferous	8	40
2	Moist Deciduous	15	60
3	Dry Deciduous	5	35
4	Wet/Semi-Evergreen	9	40
5	North eastern Region	50	45

Table 1. 2: Susceptibility and vulnerability of Indian forests to wildfire

1.1.3. Impact of Forest Fire

Majority of the fires in India are caused by humans (Bahuguna 2002). The impact of forest fire, especially in Indian context, has different perspectives – ecological, economic and social. These include - loss of timber, fuel wood and fodder; loss of natural regeneration, bio-diversity & wildlife habitat; global warming; affect on soil development, nutrient circulation and increased soil erosion; changed rates water & water circulation; etc (Rodgers, 1986). Estimated average direct annual loss due to forest fires in country is Rs.440 crore (US$ 100 millions approx) (Bahuguna & Singh 2000).

Forest Fires in India have been subjected both to natural as well as man-made causes. The adaptations for fire tolerance in trees of the deciduous forests provide evidence for long-term exposure to fire due to its thick corky, reticulate bark, thickened pods and seed coats, die back habits in seedlings etc (White, 1976). Ecologists believe that the role of man in clearing, grazing and burning of the forest areas over the past several thousand years has led to the development of the anthropogenic grasslands, scrublands and savannas (West, 1965). Pastoralists have traditionally burnt forest areas to improve short term grazing values. Tribal peoples with hunting and gathering cultures and shifting cultivators, use fire to facilitate hunting, honey collection, travel, vegetation clearing, collection of shed antlers etc. (Ramakrishnan, 1985; Johnsingh, 1986). In recent times, fire has become an integral part of non-timber forest produce (NTFP) collection. It is apparent that as the number of people using the forest environment has increased, so the frequency of fire as well. In the past, fires may have been caused by lightning strike, by rock fall or by friction between bamboo culms, but such fires would have needed adequate tinder dry fuel at the site of an infrequent occurrence such as lightning. Today, virtually all forest fires are man made - intentional or accidental.

In India, intentional fires are set in different parts of the country for various reasons (site-specific). In northern region (central & western Himalayas), people set fire mainly in pine forests (*Pinus roxburghii*) in summers for getting herbaceous growth of fodder during monsoons. In northeastern region, natives practice slash and burn practice of shifting cultivation (‘Jhum’). In central India, fire is used for clearing the forest floor prior to the collection of flowers and fruits of *Madhuca indica* (mahua flowers) or in stimulating a fresh flush of leaf crops such as *Diospyros melanoxylon* (tendu leaves). Fire is also set by tribals in this region to propitiate the local deity, ‘Damaar’. In Western region, tribal people practice ‘Raab’ cultivation, in which, dried biomass is burnt in-situ and they use ash as fertilizer. They also burn forests on the birth of a male child. In South India, especially in Western Ghats, fires are set in the upper slopes before monsoons, to fertilize agricultural fields down slope. Tribals in this region also put fire for collection of NTFP like shed antlers of deer, honey etc. (WWF-India Report, 2003; Ramakrishnan, 1985; Johnsingh, 1986). Accidental forest fires happen mainly during burning of crop remains in agricultural fields. It also happens during fire tracing works by the Forest department. Quite often, it is due to the careless tourists throwing cigarette butt, or cooking on the roadside or during campfires etc. (Semwal & Mehta, 1996)

1.1.4. Forest Fire vis-à-vis Protected Area Conservation

The continuous monitoring of the occurrence of forest fires in the Protected Areas (PA) is of paramount importance. Across the nation, national parks and forests have updated their fire management plans based on the ecological assessment of the problem and available infrastructure and resources (Rawat, G.S, 2003). A fire management policy in a PA must reflect the overall objectives or conservation goals of that area. Most PA's have a commitment to the maintenance of species and communities, or diversity or naturalness of the area. In majority of the PA's, focus of conservation is on a target species or a range of species. There are also subsidiary objectives which maybe maintenance of the naturalness or geomorphic attributes or maybe providing natural resources as benefits to the people. Naturalness is a difficult concept especially in context of the PA's in India, which are smaller in size and subject to considerable peripheral biotic pressures. Fire management in PA's in India involves two broad aspects:

- Suppression of all wild fires
- Use of fire as a management tool

Foresters and wildlife managers throughout the country are unanimous on the suppression of all wild fires. The policy is based mainly on consideration to harmful effects on forest regeneration, damage to trees, impoverishment of soil, increase of erosion, loss of habitat, vulnerability of young wildlife (Sawarkar, 1986)

1.1.5. Geo-information System approach

Fire Modelling is done to have the most effective system of fire management and at the same time to reduce its deleterious effect on ecosystems, communities and landscapes. Landscape simulation models are widely used to study the behaviour of ecological systems (Michael C. Wimberly, 2004). Pattern of forest fire spread are modelled using fine-scale mechanistic or broad-scale probabilistic approach (McCormick, Bradner, Allen 2002). Former looks at the small-scale constraints (e.g. percent moisture in fuel) that enable the fire to keep burning whereas in the latter, fire spread is determined by the size and connectedness of fuel patches distributed across the fire landscape. Innumerable forest fire spread models exist for taking decision towards fire management using the spatiotemporal database system. Current models do not account for the causative factors of forest fire occurrence.

Forest fire research can be considered as one of the most appropriate areas, where Geographic Information System (GIS) approach can be effectively applied. GIS can take definite advantage of the computer's capability in processing, storage and retrieval of immense data. The use of the GIS approach facilitates in integrating several variables in order to establish and focus on the problem. At the same time, it makes it possible to update or retrieve spatial information in different ways included in the database, to develop various models. It has been stated that when it comes to spatial-decision aid, the analytical capability of the GIS has to be enhanced in respect of semi-structured problems involving subjective judgements (Beedasyl, Jaishree and Whyatt, Duncan 1999). This can be strengthened by any GIS application, which is most appropriate for that site-specific condition.

The purpose of this study is to develop a new and effective Geo-information system approach for forest fire likelihood based on major causative factors for fire occurrence. It is proposed to develop forest fire likelihood model and evaluation models for area value and mitigation strategy based on the same. Finally, customized output will be developed for easy visual perception and retrieval of information based on query.

1.1.6. The Forest Fire Terminology

The terms 'hazard' and 'risk' have been formally associated with fire management since the beginning of modern science in the 1920s (Hardy 2005). There exist various definitions and metrics to express the two terms. The improper use of the terms like 'hazard', 'risk', 'danger', 'vulnerability', 'severity' etc may convey different meanings and may result in misunderstandings (Bachmann and Allgower, 2000).

1.1.6.1. Fire Risk

Fire Risk is the combination of likelihood and the consequence of the specified hazard being realized. It is a measure of harm or loss associated with an activity (Boonchut 2005).

More specifically as per definition of United Nations ISDR (2002), risk is the probability of harmful consequences or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable/ capable conditions

Risk is conventionally expressed by the equation:

Risk = Hazard x Vulnerability

1.1.6.2. Fire Hazard

Fire Hazard is the inherent characteristic of a material condition or activity that has the potential to cause harm to people, property or the environment (Boonchut 2005).

As per definition of United Nations ISDR (2002), hazard is a potentially damaging physical event, phenomenon and/ or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

1.1.6.3. Fire Vulnerability

Fire Vulnerability is the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a particular hazard and expressed on a scale ranging from 0 (no damage) to 1 (total damage) (Castillo 2004).

As per definition of United Nations ISDR (2002), vulnerability is a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of a community to the impact of hazards

1.1.6.4. Fire Severity

Fire severity refers to the magnitude of significant negative impact on wildland systems (Simard, 1991). Fire severity has everything to do with the effects of a fire on wildland systems (Hardy 2005).

1.1.6.5. Fire Likelihood

Fire Likelihood is expressed either as a frequency or as probability (Castillo 2004).

1.2. Research Problem

Disturbances in the PA could be managed and unmanaged. Most of the unmanaged disturbances are the result of high biotic pressures and human factors, which influence the PA conservation. Forest fire happens to be one of the key disturbances hampering PA conservation. Current forest fire models do not account for the human factor with such significance. Majority of the probabilistic models integrate only the location of human disturbance as one of the factor and rest are spread related factors. However, none of the model so far has addressed the issue from the perspective of "causative factor/s" for the likelihood of fire occurrence and effective area available for that factor to operate. We do not have models, which integrate area value along with fire likelihood for arriving at most appropriate mitigation strategy.

1.3. Research Motivation

The incidence of forest fires in the country is on the increase every year. The major cause of this failure is the piecemeal approach to the problem. We have always looked at the problem from the perspective of addressing the same without going into the actual causes. Both, the scientific focus and the technical resources required for sustaining an appropriate mitigation strategy are deficient.

Major motivation for undertaking this study comes from the professional background in dealing with the problem and its role in biodiversity conservation. Issue of fire can be thought in relation to the natural or socio-cultural values in any PA. The fire models developed so far are basically fire-spread models and no model speaks of the causative factor as the significant factor in the likelihood of fire occurrence. In the study conducted by G.S. Rawat (2003), further research potential has been suggested on this perspective.

1.4. Research Objectives & Questions

1.4.1. Main Objective

The main objective of the research is to evaluate likelihood of the forest fire considering major causative factors and their visualization for evaluation of conservation measures.

'Likelihood' here refers to the chance of area getting burnt as a result of a particular causative factor. 'Major causative factor' refers to those factors, as a result of which, area is getting burnt regularly. The factors could be of human and non-human origin. 'Visualization' refers to the easy visual perception of the information using GIS customization. 'Conservation measures' refers to the management interventions taken as a part of mitigation strategy.

1.4.2. Sub Objectives

i. To identify the possible causative factors for forest fire occurrence.
ii. To evaluate forest fire likelihood by developing a forest fire likelihood model.
iii. Establish an evaluation model for evaluating area value and mitigation strategy.
iv. To develop a customization tool for visualization of forest fire mitigation strategy.

1.4.3. Research Questions

To achieve the objective and sub-objectives, following research questions need to be answered:

Sub-Obj. i): To identify the possible causative factors for forest fire occurrence

1. What are the possible causative factors for forest fire occurrence?
2. How to identify the major causative factors responsible for forest fire occurrence?
3. How to identify forest fire occurrence as a result of that particular factor?
4. How to identify the anti-causative agents (constraints)?

Sub-Obj. ii): To evaluate forest fire likelihood by developing a forest fire likelihood model

5. What are the data requirements for developing the forest fire likelihood model?
6. How to realistically assess the likelihood of forest fire from the model?

Sub-Obj. iii): Establish an evaluation model for evaluating area value and mitigation strategy

7. How additional factors can be incorporated for developing an evaluation model for area value and mitigation strategy for conservation?

Sub-Obj. iv): To develop a customization tool for visualization of forest fire mitigation strategy

8. How to visualize the outcome based on spatial and non-spatial query through interactive GIS customized tools and menus?

1.5. Conceptual Model

For addressing all the research questions, the proposed conceptual model is given in the figure 1.4.

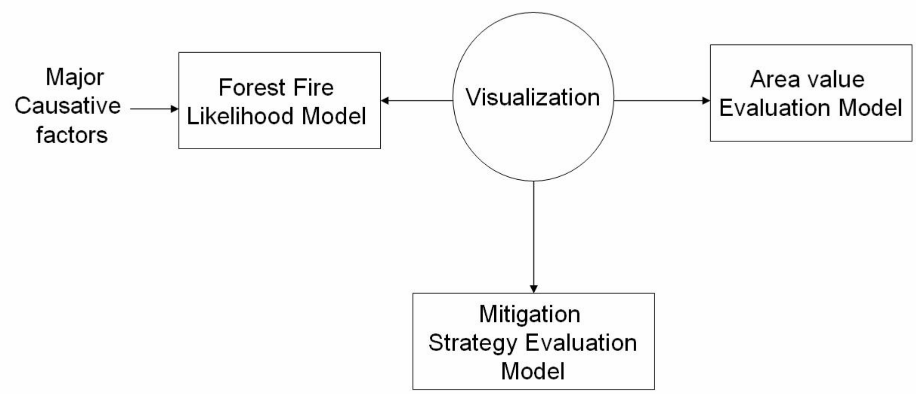


Figure 1. 4: Diagram showing visualization of all the models

The conceptual model envisages first the development of the Forest fire Likelihood model after identification of the major causative factors. Subsequently, Area Value and Mitigation Strategy models will be developed and evaluated for different scenarios. Finally, the inputs from all the models will be utilized for developing interactive GIS customized tools and menus.

1.6. Research Design

The proposed design of the study is as under:

1.6.1. Pre-Field Work

1.6.1.1. Literature Review

As per the proposed research objective, the literature review will be carried out on the following aspects:

- Agents responsible for the forest fire, both , natural and man-made
- Forest Fire Risk Zonation including fire hazard and vulnerability
- Modelling approaches – mechanistic, probabilistic and other approaches
- Criteria for Evaluation

- GIS Customization for easy visualization

1.6.1.2. Pre-processing & Standardization of the data

The requirements of the dataset are both spatial as well as non-spatial. The scope of the study is such that it needs more of secondary data from the Tamilnadu Forest department as well as satellite images from National Remote Sensing Agency (NRSA). The primary data is restricted to the procurement of the details related to certain causative factors of forest fire occurrence.

1.6.2. Field Work

This is for the collection of field information related to the causative factors of fire established through literature review and onsite details related to the study work.

1.6.3. Post Field Work

This phase incorporates analysis of the data, designing and implementation of the models and GIS customization of the results for easy interactive visualization.

1.7. Structure of the Thesis

Chapter 1 introduces the background & justification, forest fire scenarios – nationally & internationally, impact of forest fire, forest fire vis-à-vis Protected Area conservation, Geoinformation System approach for the problem and important fire terminology. It spells out the research problem, motivation, objectives, sub objectives and research questions. In addition to the conceptual model, it gives the research design and structure of the thesis.

Chapter 2 gives literature review with focus on agents responsible for causes of fire & anti-causative agents. It also deals with the forest fire risk zonation, various modelling approaches, evaluation criteria and GIS customization.

Chapter 3 is about the study area with the details on location, geomorphology, climate, vegetation, wildlife, past management practices. It also gives the details on the collection of spatial and non-spatial data.

Chapter 4 is about the methodology with focus on pre-processing and standardization of the data, identification of causative & anti-causative agents, major and critical factor responsible for fire occurrence. It also deals with the designing of the likelihood model, evaluation models including area value and mitigation strategy models. It also provides the data requirements and standardization of parameters for the models. Finally, it provides the designing of structure for GIS customization.

Chapter 5 deals with the analysis and implementation of the models. It identifies various variables for the likelihood model including pair wise comparison, generation of knowledge matrix & fire risk scenarios. It also details the calibration, validation and sensitivity analysis of the model. It identifies parameters for the evaluation models - area value and mitigation strategy and spells out generation of matrices and prioritization using GIS analysis. It also gives GIS customization using Map Objects for interactive visualization, menus driven tools and conducting spatial & non-spatial queries.

Chapter 6 is about discussion on the roles of causative factors & anti-causative agents, importance of likelihood model using temporal data, significance of the area value and mitigation strategy model including GIS customization.

Chapter 7 provides general conclusions and addressing of research objectives vis-à-vis results. It also gives recommendations for the study area as well as for further research including final remarks.

2. Literature Review

This chapter provides the Literature Review conducted relevant to the scope of the thesis topic. It gives the background & spells out agents responsible for causes of forest fire. Both natural (mainly lightning) as well as man-made (forest exploitation and disturbances) reasons have been dealt in detail. It also provides the anti-causative agents instrumental for retardation or non-fire in the area. It also describes the basis of fire risk zonation. The chapter provides an understanding on the various modelling approaches. It deals with the mechanistic and probabilistic approaches and describes the various types of model with the examples of fire related models. It also spells out estimation of Area value and basis for fire damage assessment. Finally, the chapter provides for GIS customization requirements with approach to the customization process and use of query language in GIS.

2.1. Background

The relationship between natural and anthropogenic processes on biodiversity requires holistic understanding. The effects and response of the system characterize the complex mechanisms that control biodiversity. The effects and the responses both vary on spatial and temporal scales (Murthy, Giriraj & Dutt, 2003). Human interventions are complex in terms of large-scale conversion to other land uses and processes, which do not involve loss of forest but have significant impact on biodiversity. The acceleration of processes such as forest fragmentation and forest fires in landscapes under intense human pressures makes it imperative to quantify and understand the effect of these processes on the conservation of biodiversity in these landscapes (Kondapani, Cochrane & Sukumar, 2004). In human-affected landscapes, the current distribution of forests is largely a result of the spatial and temporal interactions between humans and their environment. Forest fire is a very strong anthropogenic disturbance (Kondapani, Cochrane & Sukumar, 2004). The nature, amount and the spatial distribution of inflammable material largely govern the character of the fire in any forest location (Goldammer, 1990). Increasing dependence on forests by humans for a variety of uses further exacerbates future fire events in the landscape (Cochrane, 2003). The spatial juxtaposition of forests and other landcovers, derived through anthropogenic land use, has a large influence on the extent and frequency of fire events on fragmented landscapes (Cochrane et al, 1990; Cochrane, 2001). The difference among forests in terms of ecological characteristics, climatic factors and associated disturbance histories makes it susceptible to forest fires. Within the Western Ghats, forest fires are frequent among the vegetation communities across the landscape (Murthy, Giriraj & Dutt, 2003).

2.2. Agents responsible for causes of forest fire

Forest fires may be one of the most important deforestation processes that may be fundamentally altering the landscape of Western Ghats. Although, innumerable efforts are underway to conserve the biological wealth of this region, these initiatives will be unsuccessful if the causative factors driving this deforestation and degradation process are not taken into account.

It is important to know as much as possible of fire causative agents. Classifying the number of fires and the area burnt due to specific fire cause is probably one of the most widely kept statistical record in US forest department (Show & Clarke, 1953). Data are not maintained in uniform fashion in all countries are within the same country.

CAUSE	Number	Percent
Natural (Lightning)	3863	49.6
Man-caused	3918	50.4
Rail-road	276	3.5
Lumbering	215	2.8
Camp-fires	318	4.1
Smokers	1795	23.1
Debris burning	206	2.6
Incendiary	179	2.4
Miscellaneous	929	11.9
Total Number of fires	**7781**	**100.0**

Table 2. 1: shows fires by causative agents in California region, USA (1943-47)

Year	No. of fires	Causes		
		Carelessness including Rail-road	Incendiary	Unknown
1922-1949	1099	104	90	902

Table 2. 2: shows forest fires in the Landes, France 1922-1949

The classification "unknown" should preferably not be used; there is a natural tendency on the part of the observers to classify many fires in this category, which are difficult or doubtful to determine (Show & Clarke, 1953)

2.2.1. Natural Causes

The natural causes of forest fires may be attributed primarily to lightning strike, even by rockfall or by friction between bamboo culms (Rodgers, 1986). Lightning ignition plays a major role in the maintenance and evolution of ecosystems. Lightning not only ignites fire but also weakens the trees, making it prone to diseases and causing physical damage to the trees (Taylor, 1973)

2.2.1.1. Early Lightning Fire Research

Plummer (1912) explained the wide range of visible effects hypothesized distinctly different "upward-going" and "down-going" flashes to ground, causing different kinds of damage to trees. Trees may be scorched, stripped of their leaves, split longitudinally or severed horizontally. Lightning, ignition studies were done in north-western area of the United States, which included western Montana, northern Idaho and parts of eastern Washington, eastern Oregon and north-western Wyoming. For this area, about 15% (864 fires) of the fires in the natural forests were caused by lightning during 1906-1911 (Plummer, 1912).

2.2.1.2. Recent Lightning Fire Studies

Recent studies of lightning caused fires are mainly due to two major data sources: organized fuel state descriptions and accurate cloud-to-ground lightning location. Fuel type and fuel state, principally moisture content have been used for establishing fire indices. Lighting location is accomplished by detecting low-frequency electromagnetic radiation emitted by lightning (Latham & Williams, 2001). McRae (1992) found no relationship between the topographic factors like elevation, slope, aspect or topographic unit and lighting fires for the Australian Capital Territory. According to Meisner (1993), lightning strikes were randomly distributed over the terrain, as were the fuel classes in the Southern Idaho between 1985 and 1991. Lightning density and fires are only loosely connected i.e. if lightning is inevitable (by definition), may not be a sufficient condition for ignition. Other factors like fuel type and moisture content must also be considered (Latham & Williams, 2001).

Interaction between Lightning and Fuels

Plummer (1912) suggested that an increase of tree conductivity due to wetting by rain had a role in forest fire. The lightning strike path usually follows the cambium layer of the tree because of high conductivity (Defandorf, 1955). Many lightning strikes to trees do not result in fire. It may cause only mechanical damage including complete destruction (Plumer, 1912; Taylor, 1969). Lightning ignition of forest fuels takes place almost exclusively in the fine fuels on the forest floor.

2.2.2. Manmade causes

It includes intentional and accidental fires by the communities in the forest areas due to various reasons.

Forest exploitation (Lumbering) - This includes fires caused by logging operations and wood processing units. Fires caused by the activities of the persons engaged in the gathering or processing of the non-timber forest produce (NTFP) are also included.

Debris burning (Clearing) - This includes forest fires, which result from the clearing of the land for any purpose. This may be for cultivation or pastoral purposes (grazing), disposal of slash etc. Throughout the tropics, this is one of the major causes of forest fires (Show and Clark, 1953). This also includes boundary clearance around plantations and estate areas.

Railroads (Railways - It includes fires started by locomotive sparks and other causes incidental to operating trains. It also envisages fires caused in the course of construction or maintenance of the roads and right of way.

Tourist activities - It includes forest fires originating from tourist or passer-bys on roads as well as rail routes because of smoking, cooking, and camping, pilgrimage etc. The incidence of such fires is normally along travel routes and hence outbreaks are usually detected.

Incendiary - It includes forest fires deliberately set to cause damage or mischief. Persons with malicious intention generally cause damage and trouble to gain employment during fire season.

Miscellaneous - Fires, which cannot be classified in any of the above reasons are included here e.g. fires started by a crashed aircraft or burning automobile of ‘fire balloons’ etc.

Accidental fires - This includes fires, that sometimes escape while undertaking controlled burning, and fire tracing works as a part of fire prevention operations. This may also include fire during burning of crop remains from agriculture fields, or during pine resin tapping.

2.2.2.1. Forest fires in India

Forest fires in India have been initiated due to natural causes as well as manmade reasons. Role of man in clearing, grazing and burning the forested lands over the last several thousand years has led to the development of the anthropogenic grasslands, scrublands and savannas (Rodgers, 1986). Pastoralists have inhabited India for thousands of years and have traditionally burnt forestlands for grazing values. Tribal communities in the forest areas have used fire in facilitating hunting, forest exploitation, clearing, shifting cultivation and NTFP collection (Ramakrishnan, 1985).

In recent times, the number of people using the forest areas has increased dramatically and so has the frequency of fire as well (Rodgers 1986). Fire has become an integral part of NTFP collection used for clearing the forest floor. In Central India, fire is used by the local communities to collect 'Mahua' (*Madhuca latifolia*) flowers and in stimulating fresh flush of leave crop such as 'Tendu' (*Diospyrous melanoxylon*). The NTFP collectors exert such a pressure that one area may be burnt three times in a year i.e. for 'mahua' flowers in March, 'tendu' leaves in April and for 'sal' (*Shorea robusta*) seeds in May (Rodgers, 1986). Different regions in the country have different causative factors. In Central Western Himalayas, natives set fire in 'Chir' pine (*Pinus roxburghii*) forests during summer season to promote tender growth of herbaceous vegetation during monsoon for fodder (WWF report, 2003). In North Eastern India, tribals set fire to forest patches as part of shifting agriculture practice, 'Jhum'. Similar threat exists in'Raab' cultivation in Western India.

In the study area, fire season is from January to March. The tribals of Mudumalai Sanctuary and adjoining Bandipur National Park set fire to facilitate their search for shed antlers of 'Chital' (*Axis axis*) and Sambar (*Cervus unicolor*) deer (Johnsingh, 1986). The poachers cause fire for having visibility and to attract animals (Menon et al, 1997). Graziers, tourists, estate people and people residing in forest enclaves also cause fire.

2.3. Anti-causative agents

The term 'firebreak' is a natural or already existing barrier, or a barrier artificially constructed before a fire occurs. The barrier is designed to prevent, stop or check creeping or running fires (Show and Clarke, 1953). Waterways, swamps, road networks etc form part of the firebreak system. Depending on the location, additional firebreaks are created for more effectiveness.

2.3.1. Types of firebreaks

Firebreaks can be quite effective in stopping the spread of ground fire. However, normal firebreak will not stop a crown fire or a big fire in heavy undergrowth fanned by high wind velocity. Sparks or burning material are often thrown ahead of the main fire and the firebreak intended to counter such occurrences will not be effective (Show & Clarke, 1953). Firebreaks and fire lines are regarded as bases from which a fire can be tackled and confined. The several types of firebreaks are:

Natural breaks - include rivers, creeks, swamps and permanent cultivation etc (Sheikh & Sawarkar, 1979; Show & Clarke, 1953). In tropical and subtropical regions, rainforest and evergreen patches form barriers against fire. It is advisable to prohibit logging operations within them; otherwise, natural green break can gradually be destroyed by the inroads of fire.

Existing roads, trails and tracks - All roads and trails, kept clear of inflammable material reduce the possibility of creeping fires getting across the road. Effectiveness is increased by clearing firebreaks along either side of the road.

Cleared firebreaks - Completely cleared firebreaks, one or two chain (20 to 40 metres) in width, in strategic sectors are created free of vegetation and inflammable material. In some countries, spraying with chemical is also a resort where the break is alongside a road (Show & Clarke, 1953). Fire lines are cut well before the onset of summer, the cut material is piled, allowed to dry and finally burnt (Sawarkar, 1986). In deciduous forest areas, the earlier cleared fire lines gather 'teak' (*Tectona grandis*) or 'sal' (*Shorea robusta*) leaf litter as a result of leaf shed, which are burnt to keep fire lines clean and effective (Sheikh & Sawarkar, 1979).

Tree covered breaks - Standing dead trees, trees with inflammable bark and combustible material on the ground are removed as part of this break (Show & Clarke, 1953). Artificial green breaks of fire resistant species like Agave etc are used as a border on roadsides to prevent fire (Tyagi, 1993).

2.3.2. Management based anti-causative factor

The management-based factors could be manned or unmanned features. Early burning practiced in some fire prone areas of southern India has met with a limited success due to the problems in maintenance of the burning schedule as well as non-compliance of sound ecological research (Srivastava, 2001). A good network of fire lines and fire watchtowers at vantage locations also help in preventive strategy. In recent times, stationing of the manned fire camps and patrolling by the present staff strength acts as an effective measure in fire prevention. The effectiveness of the same is gauged from the perspective of their strategic location, available camp strength and daily patrolling in the area (Srivastava, 2001).

2.4. Forest Fire Risk Zonation

The zone is a practical concept and aid to fire planning. Likely zones are along major thoroughfares, where intensive logging operations are carried out or maybe where grazing interests adjoin forest areas. According to Show and Clarke (1953), the record of fire occurrence over a period of years exhibits a definite pattern of occurrence as under:

- fires are concentrated in areas adjacent to villages, roads, railroads, logging operation etc
- a zone of scattered points exist around these concentrated areas
- there are areas with no fires but for the spread from adjoining areas

The documentation of these fire occurrences on maps is of immense assistance in formulation of fire management strategy. Devising of any fire management strategy requires clear understanding of the terms like 'hazard' and 'risk'.

2.4.1. Fire Hazard

According to the National Wildfire Coordinating Group (NWCG, 2003), fire hazard is defined as a fuel complex constituted by volume, type, condition, arrangement and location that determines the degree of ease of ignition and the resistance to control. Bachmann and Allgower (2000) use the term 'hazard' not to represent any precondition for a specific process, but to refer to the process itself i.e. wildfire is the hazard. There maybe variety of classifications for 'fire hazard', it applies only to the fuel itself, and does not include the weather or environs in which the fuel is distributed (Hardy, 2005). To cause any sustain fire, it requires fuel, heat and oxygen. In addition, fire behaviour is affected by fuel, weather and topography. To further emphasize the exclusion of weather from 'fire hazard', Ministry of Forests (MOF, 1997), Province of British Columbia (Canada), define 'fire hazard' as the potential for fire behavior for a fuel type, regardless of the fuel type's weather-influenced fuel moisture content. It is based on the physical fuel characteristics i.e. fuel arrangement, fuel load, condition of herbaceous vegetation and presence of elevated fuels (MOF, 1997). According to National Research Council (NRC), hazard is defined as "an act or phenomenon with the potential to do harm" (NRC, 1989). The potential to do harm implies that a ‘causative agent’ is needed in order to convert the potential to realized harm. If no causative agent is available, the potential for a pre-existing hazard to result in harm is nil (Hardy, 2005). As per National Academy of Sciences (1983) ‘hazard’ is considered as events or conditions (both internal and external to the system) whose occurrence or existence might result in undesired consequences. Current methods for assessment of ignition potential often fail to alert forest/ wildlife managers to the severity of fire hazard at remote locations and over larger geographic areas. Remote sensing may have utility for fire hazard assessment in drought stress (Chaparral) vegetation type (Cohen, 1991). The availability of fuel type is the key factor in fire ignition and fire spreading (Darmawan, 2001).

2.4.2. Fire Risk

Fire risk is the chance that a fire might start, as affected by the nature and incidence of causative agents (Hardy, 2005). According to Deeming et al (1972), the National Fire Danger Rating System (NFDRS), classifies two sources of Fire risk:

- Lightning Risk (LR)
- Man-caused Risk (MCR)

In the case of LR, an index is determined based on lightning activity experienced the previous day and expected for the current day on the probability scale of ignition. MCR is derived through relative level of human activity and causative agents of human caused ignitions including other scalars. The cumulative evaluation of two indices comprises total risk (TR).

2.5. Modelling Approaches

Wildfire occurs over a continuous spatio-temporal range (Simard, 1991). The elements of the fire environment - fuel, weather and topography - also vary continuously over the range of scales. Most of the fire models developed relate to the conifer-dominated forests. Ecosystem differences (e.g., wind/elevation interactions, landform and cover) may make these model structures inappropriate for other areas. Increasing human presence on and around forested lands in the region raises the potential for conflicting land management scenarios (Plevel, 1997). Therefore, forestland managers recognize the need for a wildfire model specifically applicable to that region. Fire probability models exist for various combinations of landscape characteristics (Alencar, et al, 2004).

Approaches to modeling wildfire spread patterns are either fine-scale mechanistic or broad-scale probabilistic (McKenzie, Peterson and Alvarado 1996). All fire models look at fire spread from the standpoint of the flames pushing the fire front along if fuels are available or wind is strong (Green, Tridgell and Gill 1990). Through repeated simulations these models can determine the degree to which a given landscape is connected (i.e., able to carry a fire), when it is above or below some critical threshold value (Green 1994). Turner and Romme (1994) spell the need for a link between fine-scale mechanistic and broad-scale probabilistic wildfire models. While each fire model has different, specific input requirements, any model of wildfire will require information on fuel, weather and topography (Fons 1946).

2.5.1. Mechanistic & Probabilistic approach

Mechanistic approaches look at the small-scale constraints (e.g., percent of moisture in fuel) that enable a fire to keep burning. In probabilistic models, fire spread is determined by the size and connectedness of fuel patches distributed across the fire landscape. Both modeling approaches use some form of fuel, climate, and topography variables. Mechanistic models lack the overlying landscape structure and variable climate that serves as context for and constraint on disturbance processes (Simard 1991). To work within a meso-scale range, both approaches extrapolate model results up- or down-scale, or aggregate fire environment variables to the desired scale of analysis (McCormick, et al 2000). Changing spatial and temporal scales of fire environment variables leads to the inherent unpredictability found in middle number systems (Allen and Starr 1982). A complex systems approach to modeling fire behavior involves not only knowing what variables are constraining fire growth at a fine scale but also which constraints are absent at a broad-scale, allowing a fire to spread unchecked.

Fire literature focuses on either the fires raging or the fires surviving, but not on both sets of constraints. Each class of model is predictive to a limited degree. Predictive modeling of fire behavior involves knowing what variables are constraining fire growth or which constraints are absent allowing unchecked positive feedback between fire and fuel. Extant fire models lose predictive power when subtle shifts in environmental variables cause a qualitative change in fire behavior. Most modeling approaches select and theorize about environmental parameters based on observations and expert knowledge. Parameters are calibrated using reasonable assumptions and probabilities (McCormick, et al 2000).

2.5.2. Other Approaches

Other recently developed approaches take the advantage of raster-based simulation concepts (e.g., cellular automata (CA) and nearest neighbor decision rules) to incorporate concepts of diffusion (Clarke, Brass and Riggan 1994), percolation (Green 1993), or contagion (Li and Apps 1996; Gardner, et al. 1996) in spreading fire across a landscape. CA is a 2-dimensional array of cells with values that represent the global state of a variable. Most CA models of fire spread require some estimate of the burn potential for each cell prior to running the model. The probabilities are often stochastic in nature, and use multiple runs to develop a map of fire risk. Cellular automata have been implemented in fire models using Rothermel's (or others) rate of spread (Karafyllidis and Thanailakis 1997), Huygens' principle (French, Anderson and Catchpole 1990), nearest-neighbor movement rules (Ratz 1995) and invasive epidemic processes (Green, Tridgell and Gill 1990).

Haykin (1994) defines a neural network as ". . . a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use." Artificial neural networks (ANN) acquire knowledge by learning from examples and store that knowledge as synaptic weights in connections (networks) between processing nodes (neurons). ANNs have the ability to model complex functional relationships predefining the behavior and interactions of all the pertinent components (i.e., the rules are not known). ANNs framework provides a comprehensive integration across scales of fire environment variables. The ANN is able to determine the equations describing those cross-scale interactions and better predict where a fire will spread as a result.

2.5.3. Various types of Models

Models can be *empirical*, such as statistical models that often have a single solution or *stochastic* that includes algorithms based on random choices. Models can also be *spatial*, in which they simulate entities. Entities refer to individuals or cells that have explicit coordinates in two or three dimensional space. However, not all spatial models are *spatially dynamic*. A spatially dynamic model includes not only explicit locations of entities, but includes processes that incorporate interactions among entities in space that in part drive change in the focal entity over time. Such models do not have a single solution. They usually run in multiple replicates to generate a mean trajectory of change (Mladenoff, 2004).

Spatial forest landscape models and landscape models and landscape models operate on a number of different focal entities. The entities may be trees with actual x, y coordinates, gaps that may be occupied by innumerable stems without explicit locations, cells or pixels on the landscape map or delineated stands or patches. In order to understand the applicability of a particular model to the forest landscape, we need to understand the broad categories of models. Various categories of broad and partly overlapping models, used in forest landscape are as under:

2.5.3.1. Equation-Based Models

Most models are in some way mathematical, but some are especially so in that they rely on equations that seek a static or equilibrium solution. The most common mathematical models are sets of equations based on theories of population growth and diffusion that specify cumulative land-use/cover change over time (Sklar and Costanza 1991).

2.5.3.2. System Models

System models represent stocks and flows of information, material, or energy as sets of differential equations linked through intermediary functions and data structures (Gilbert and Troitzsch 1999). These models represent human and ecological interactions. They are dependent on explicit enumeration of causes and functional representation and accommodate spatial relationships with difficulty (Sklar and Costanza 1991).

2.5.3.3. Statistical Techniques

Statistical techniques are a common approach to landscape modelling, given their power, wide acceptance, and relative ease of use. They include a variety of regression techniques applied to space and more tailored spatial statistical methods (Ludeke, Maggio, and Reid 1990).

2.5.3.4. Expert Models

Expert models combine expert judgment with non-frequent probability techniques such as Bayesian probability or Dempster-Schaefer theory (Eastman 1999) or symbolic artificial intelligence approaches such as expert systems and rule-based knowledge systems (Lee et al. 1992). These methods express qualitative knowledge in a quantitative fashion.

2.5.3.5. Evolutionary Models

Within the field of artificial intelligence, symbolic approaches such as expert systems are complemented by a biologically inspired evolutionary concept. Artificial Neural Networks and evolutionary programming, are finding their way into Landscape models (Mann and Benwell 1996).

2.5.3.6. Cellular Models

Cellular models (CM) include cellular automata (CA) and Markov models. Each of these models operates over a lattice of congruent cells. The system is homogeneous in the sense that the set of possible states is the same for each cell and the same transition rule applies to each cell. Time advances in discrete steps, and updates may be synchronous or asynchronous (Hegselmann 1998). In CA, each cell exists in one of a finite set of states, and future states depend on transition rules based on a local spatiotemporal neighbourhood. Many CM assume that the actions of human agents are important, but do not explicitly model decisions. Others explicitly hypothesize a set of agents coincident with lattice cells and use transition rules as alternatives to decision making. CM have utility for modelling ecological aspects, but face challenges when incorporating human decision making (Hegselmann 1998).

2.5.3.7. Hybrid Models

Hybrid models combine any of the above-mentioned techniques, each of which is a discrete approach unto itself. A prime example is estuarine land-use transition modelling that has an explicit, cellular model tied to a system dynamics model (Costanza, Sklar, and Day 1986).

2.5.3.8. Agent-Based Models

Where cellular models are focused on landscapes and transitions, agent-based models focus on human actions. Several characteristics define agents: they are autonomous, they share an environment through agent communication and interaction, and they make decisions that tie behavior to the environment. Agents have been used to represent a wide variety of entities, including atoms, biological cells, animals, people, and organizations (Weiss 1999).

2.5.3.9. Multi-Agent Systems Model

Multi-Agent System model consists of two components. The first is a biogeophysical and ecological aspect of cellular model and the second is an agent-based model to represent human decision-making. The cellular model is part of the agents' environment, and the agents in turn act on the simulated environment (Parker et al, 2002)

2.5.4. Fire regime models

Numerous fire models exist to examine the effects of fire regime like fire frequency, severity, and extent of fire disturbances on the landscapes. Different models have varying purposes, and therefore, they use different approaches to simulate fire occurrence, behavior and effects (Yang et al, 2004). Statistically based approaches use the distribution of fire frequency and fire size to simulate a given fire regime. The approaches have evolved from the theory of Weibull and exponential fire history models (Van Wagner, 1978; Johnson and Van Wagner, 1985). They are used in many models such as DISPATCH (Baker et al., 1991), REFIRES (Davis and Burrows, 1994), FLAPX (Boychuk and Perera, 1997), ON-FIRE (Li et al., 1997), LANDIS (He and Mladenoff, 1999), and LADS (Wimberly et al., 2000). All these models simulate fire ignition and extent of fire occurrence in spatial domain from certain probability distributions. The distributions used to model fire frequency and fire size are different. For example, the fire frequency distribution in DISPATCH is uniform while the distribution in LADS is Poisson, and the fire size distribution in LANDIS is lognormal while the distribution in LADS is exponential.

The term *fire occurrence* refers to an active fire that happens when the fire begins to spread through the forest fuel complex as a surface fire or a crown fire and emits significant amounts of smoke and energy (Anderson et al., 2000). The term *fire ignition* also refers to fire occurrence. Other terms such as potential fire ignition (Davis and Burrows, 1994) or fire source (Antonovski et al., 1992) are also used. A statistical approach divides a fire occurrence into fire ignition and fire initiation (Li, 2000). Delineating fire ignition from fire occurrence helps to separate the abiotic factors (climate, topography, and human activities) from the influences on fire spread of biotic factors (fuel accumulation and vegetation structure). A fire occurrence begins with an ignition from an external heat source that heats the forest fuel complex up to its ignition temperature. Fire ignition agents are either natural (lightning) or anthropogenic (e.g., arson or accidental). A fire initiation event starts with the ignition with burning of a certain area equal to the grain-size of the model (Li, 2000). Whether a fire ignition can result in fire initiation is dependent on the fuel loading, fuel arrangement, and fuel moisture content. Statistically based fire regime models are not flexible enough to simulate the full range of fire regimes observed in forested ecosystems. Modeling of fire ignition and calculation of fire probability in these models cannot fully account for the fire frequency distribution of various fire regimes. Fire probability in fire regime models is the probability of a fire occurrence given the presence of an ignition. It is dependent on the fuel build-up, often assumed as a function of time since last fire. Thus, fire probability is different from fire hazard. Many fire regime models assume that fire probability equals fire hazard (Yang et al, 2004). Hierarchical modeling in statistics refers to modeling a complicated process by a sequence of relatively simple models placed in a hierarchy (Casella and Berger, 2001). Because statistically based fire regime models simulate fire occurrence as two consecutive stages, it is natural to use the theory of hierarchical modeling to model fire frequency distribution as a mixture distribution (Yang et al, 2004).

2.5.4.1. Fire frequency model

Fire frequency is the number of fires per unit time in a specific area (Agee, 1993). Larger the size of the specific area, higher is the fire frequency (Johnson and Van Wagner, 1985). *Fire interval* is the elapsed time between two successive fires in a specific place (McPherson et al., 1990). *Fire cycle* is the number of years necessary for an area equal to the entire area of interest to burn; some sites may burn several times, while others do not burn at all (Johnson and Van Wagner, 1985). Fire cycle is also known as fire rotation (Agee, 1993). The relationship among the size of study area (AREA), mean fire size (MFS), mean fire frequency (MFF), and fire cycle (FC) is depicted by the following equation (Boychuk et al., 1997).

$$AREA = MFS \times MFF \times FC$$

If fire hazard is constant, then fire interval has an exponential distribution, and fire frequency is distributed as a Poisson process (Van Wagner, 1978). Fire interval is widely modeled as a Weibull distribution because it permits fire hazard to increase or decrease with time since last fire (Johnson and Van Wagner, 1985; Clark, 1989; Johnson and Gutsell, 1994; McCarthy et al., 2001). The exponential and Weibull models are fixed and the sampling occurs from a single fixed probability distribution (Polakow and Dunne, 1999). On the other hand, hierarchical model incorporates variability about the parameter estimates and it separates fire ignition from fire occurrence as most of the other models.

2.5.4.2. Fire hazard model

The GIS models for forest fire hazard have been developed envisaging fuel type (FT), dried vegetation index (DVI), elevation (EL), gradient (GR), aspect (AS), and buffer road (BR) (Darmawan, 2001). The various approaches include:

Model 1 – All the variables have the same weight

Model 2 – Fuel type derived from land use/ cover has a weight twice higher than the other variables

Model 3 – Fuel type derived from land use/ cover has a weight higher followed by gradient

Model 4 – A model derived from Dried Vegetation Index and all the variables have the same weight

Model 5 – A model derived from DVI has a weight twice higher than other variables

Model 6 – A model derived from DVI has a weight higher followed by gradient

2.5.4.3. LANDIS model

Understanding fuel dynamics having large spatial (10^3-10^6 ha) and temporal scales (10^1-10^3 years) it is significant in wildfire management (He, H. S. et al 2004). The LANDIS model of forest landscape disturbance and succession was developed since the early 1990s as a research and management tool. LANDIS is a raster model, and operates on landscapes mapped as cells, containing tree species, age, classes (Mladenoff, 2004). In LANDIS model structure, a landscape is divided into equal-sized individual cells or sites. Each site (i ,j) resides on a certain land type and includes a unique list of species present and their associated age cohorts. The LANDIS fuel module uses fine fuel, coarse fuel and live fuel for each cell on a landscape. Fine fuel is derived from vegetation types (species composition) whereas coarse fuel is derived from stand age in combination with disturbance history. Live fuel also known as canopy fuels may be ignited in high intensity fire situations such as crown fires. Potential fire risk is determined by the potential fire intensity and fire probability, which are derived from fire cycle (fire return interval) and the time since last fire. A major objective of LANDIS is to stimulate changes on large forested landscapes, where input data may be coarse, such as those associated with fuel data. LANDIS is designed to operate over large spatial (10^6 ha) and temporal (1000s in year) scales at a wide range of environment settings (He, H. S. et al 2004).

2.5.4.4. Fuel Models

Rothermel's original equations assume that the fire is burning through a uniform fuel, across a flat terrain, and with no wind. These simplifying assumptions made the original specification of fire behavior equations possible. Mechanistic fire models based on Rothermel's equations inherited those simplifying assumptions. The floating scale approach to fire and fuel modeling has implications for local, regional and state forest planning, and can be useful in rapid assessments of fire risk, pointing to areas requiring more finely scaled analyses.

2.5.4.5. BEHAVE and FARSITE Models

In the U.S.A., the BEHAVE model is the fire simulation tool most often used to predict fire behavior. The mathematical formulas behind the system are representative for homogenous ecosystems and fuel arrangements. BEHAVE considers various assumptions viz. homogenous fuel bed; constant slope, aspect, wind velocity and direction; flaming front; non-influencing ignition source or suppression activities (Rothermel 1972). BEHAVE contains a module to simulate fire in different types of ecosystems, called fuel models. This allows a classification of every land cover type into standard fuel types e.g. grass fuels, forest fuels, forest fuels with slash etc.

The FARSITE model contains the same algorithms and formulas as BEHAVE, but can be used to simulate fire on diverse landscapes with different fuel models. The input data sets contain information about elevation, slope, aspect, fuel type, crown closure, stand height and crown bulk density (Finney 1998). The fire is modeled as a moving elliptical wave and the shape is determined by wind and topography (Richards 1990, 1995). The described methods and simulation tools offer a possibility to react on disasters such as forest fires. They allow an effective use of available resources and can give further insight in forest fire effects on the vegetation.

2.6. Evaluation of Area Value

Modelling of Area value is more qualitative and less verifiable. Economic valuation of goods and services provided by the species/ ecosystem/ landscape is of immense value and is quite difficult to comprehend. The valuation of ecological resources, particularly in economic terms, is accorded top-most priority in international sphere (Munasinghe and Lutz, 1993). The major difficulty of estimating economics of Protected Areas is the lack of appropriate methodologies for estimating non-marketed goods and services provided by these areas. Broad categories of values associated with the PA's (Sawarkar, 2002) are as under:

No.	Value Category	Illustrative Constituents
1	Real or Economic	Non-timber forest produce (NTFP), grazing, water etc
2	Biological	Endangered species of plants and animals; fragile communities
3	Ecological process	Catchment capability, soil conservation, carbon sink etc
4	Conceptual	Endemism, rarity, diversity
5	Physical attributes	Fragile geology, geomorphology, fossils, springs etc
6	Recreational	Scenic landscape, wilderness experience, wildlife watching
7	Scientific	Research opportunities, medicinal plants, ecological monitoring
8	Educational	Nature interpretation, conservation awareness
9	Assorted	Cultural, religious, historical etc

Table 2. 3:Categories of Values in Protected Area (as per Sawarkar, 2002)

2.6.1. Total Importance Value

Importance value is derived based on primary uses. The uses considered are forage for livestock, medicinal use, human food, fuelwood, timber, charcoal etc. The secondary direct benefits include production of oil and fibre, mats making, ropes and baskets, tanning leather etc and indirect benefits like shade and hedges, soil stabilisation, nitrogen-fixing roles, and of course the scientific importance (Belal and Springuel, 1996). Total Importance Value is calculated by assigning a range of 0-10 points to economic value for each use as below (Roy et al, 2000):

$$TIV\% = \frac{U1 + U2 + U3 ....U_n}{numberofuses \times \max imumvalue}$$

where, TIV% is Total Importance Value and U is Importance Value for each particular use (e.g. timber, fuelwood, food etc)

However, TIV, though appears natural, is quite arbitrary and needs to be applied with caution.

2.6.2. Total Economic Value

The concept of Total Economic Value (TEV) of the Protected Areas has been developed to assess the full range of benefits provided by goods and services (both marketed and non-marketed) of natural areas (Dixon and Sherman, 1990). TEV is the sum of use values (UV) and non-use values (NUV). Use Values are the values that are associated with the use of a resource. Use Values have three major components: Direct Use Value (DUV), Indirect Use Value (IUV) and Option Value (OV) (Barbier, 1991; Pearce and Moran, 1994). DUV generates when the goods and services of ecological resources are used directly. It can be consumptive or non-consumptive. Sustainable utilization of timber, firewood, grazing, medicinal plants, fruits, nuts, roots, leaves, etc are consumptive use. Non-consumptive uses include ecotourism or research/ education etc. IUVs are associated with the utilization of Protected Areas indirectly. IUVs are non-marketed services of these areas. This include watershed benefits such as recharging of ground water, flood control, regulation of stream flows; ecological services such as fixing of nutrients, assimilation of waste, pollution control, carbon store and other microclimatic functions; evolutionary processes including the maintenance of biodiversity. Option Value is associated with the benefit received by retaining the option of using a resource in the future by protecting or preserving it today, when its future demand or supply is uncertain. Non-Use Values are derived from the WTP (Willingness to pay) without any kind of use of ecological resources during the present and future (Manoharan & Dutt, 1999).

There are two major kind of non-use values viz. Bequest values (BV) and Existence values (EV). Bequest values originate when people are willing to pay to conserve the benefits of ecological resources by knowing that it would benefit their offspring or future generations. Existence Values are generated simply by the knowledge of the existence of resources and its benefits.

$$TEV = UV + NUV$$
$$= (DUV + IUV + OV) + (BV + EV)$$

TEV approach has a number of limitations. First, appropriate methodologies are not readily available to estimate all components of TEV. Second, the probability of double counting is very high during the aggregation of various values of these benefits. Thirdly, there are problems in summing up values derived from different approaches (Manoharan & Dutt, 1999). In this context, it would be worthwhile to focus the economic valuation of selected benefits where methodologies are readily available.

2.6.3. Fire Damage Assessment

Evaluation and economic analysis of forest fire damage, requires that the consequences of fire be known and expressible in common terms. In forests, determining values at risk is not so simple. The unit of commonality is usually monetary, although some analysts have proposed working with units of “satisfaction” and “dissatisfaction” to avoid the difficulties inherent in placing money values on some forest outputs (Nautiyal and Doan, 1974).

The economic, as opposed to the physical, biological, and ecological consequences of fire depend almost entirely on the management intent. Fire damage assessment becomes more complicated when a forest property is managed for multiple benefits rather than purely for timber production. Logically, the values being protected from fire should include only those values that are, at risk should a fire occur.

According to Craig et al (1946), in a study made in the United States, the damaging effects of fire can be considered in the following categories:

Timber values - marketable and young growth, including regeneration; effect on stand composition; deterioration or improvement of the site for timber growth.

Watershed values -flood, erosion and sedimentation damage attributable to fire; reduction in groundwater reserves and in base stream flow.

Wildlife values - loss of game birds and animals; the effect on their habitat.

Recreational values - damage to established facilities and the effect on recreational use of forest land.

Grazing values - effect of fire on range values and use.

Socio-economic values - effect of loss of biodiversity on the social and economic pattern of the area.

Value on a good or service envisages four general types of indicators. These are market price, conversion return, replacement/ opportunity cost and user cost. Market price is the preferred measure of value if a free and competitive market exists. In valuation by conversion return, a resource that serves as an input for some derived product is valued at the price of the derived product minus all immediate costs of production. Opportunity cost is the value foregone by investing in one resource instead of another. Replacement cost is one example of opportunity cost since it represents benefits foregone by replacing the resource. User costs are the costs incurred by the user of a good or service that must at least equal the value of the resource or the user would not have incurred the costs.

2.7. GIS Customization

Customization is the process of adapting a system to an individual specification. GIS can be customized in different ways. GIS database is constituted with geographic data in vector or raster format and non-geographic data as semantic representations (Antenucci, 1991). Users normally interact with the GIS software via a typical graphical menu driven icon-based graphical user interface (GUI). Selections from the GUI make calls to geo-processing tools. The tools in turn make calls to the data management functions responsible for organising & managing data stored in a database (Rao, 2003). It is widely recognized that along with data capture, customization is usually the most expensive element of an operational GIS (Antenucci, 1991).

All GIS implementations, including those involving customization, have in common the fact that they must meet user requirement.

2.7.1. Development of Prototype

Prototype design is based on the characteristics of datasets. The visualization of complex geo-phenomenon in itself is a challenging issue as it involves number of parameters. Landuse change happens to be one such complex phenomenon (Biswas, 2004). Prototyping seems most useful in the areas of user interface design, performance estimation and functional requirement analysis (Rao, 2003). The design concept used is based on spatial and temporal characteristics of data which is determined by pixel value. Changes in spatio-temporal data mainly consider location, attribute and geometrical change. The approach envisaged in designing the prototype is such that it supports to explore locational and attribute changes with the help of animation and linked graphics (Biswas, 2004).

2.7.2. Query languages in GIS

To build simple and user-friendly interfaces, the main characteristic of spatial data is to be graphical. Therefore, visual languages are well suited for these applications. The main approaches include

- Textual approaches such as natural language and extensions of SQL and
- Non-textual approaches like tabular, graphical and visual query languages.

The expression of a query can be complex and the dialog with the end-user can be too verbose. This approach may be a good complement for other approaches like graphical or visual languages in order to solve ambiguities (Lbath, 1995). Many propositions have been done to extend the SQL query language in order to manage spatial data: introduction of new data types and operators, query optimization, etc (Egenhofer. 1994). Tabular approaches can be seen as extensions of QBE (Query-By-Example). The end-user has to be aware of the underlying model in order to query the database (Lbath, 1995).

Graphical languages are based on the use of symbols representing the data model concepts without any metaphorical power (Dennebouy, 1995). Visual languages use metaphors to show the concepts and take the mental model of the end-user into account. Two kinds of visual query languages include:

- the end-user draws a pattern using a set of static icons like in the Cigales query language
- the end-user makes a drawing directly on the screen using the blackboard metaphor like in the sketch query language (Meyer, 1993).

Thus, the use of visual language in a technical context (oriented design) and visual query language (oriented end-user) leads to a great contribution to the customization of GIS.

3. Study Area

This chapter provides an overview on the study area with the details on location, geo-morphology (drainage), climate (temperature and rainfall), water management, flora and fauna. It spells out the justification for selection of the study area. The relevant details on the past working and management practices have been included. It also gives the necessary details on both spatial as well as non-spatial data collection.

3.1. About the Study Area

3.1.1. Location

The Mudumalai wildlife Sanctuary and national park lies between latitudes 11° 30' and 11° 42'N and longitudes 76° 22' and 76° 45' E in the State of Tamil Nadu where the boundaries of the three southern states of Kerala, Karnataka and Tamil Nadu meet. It is located at 1000 metres altitude high plateau at the base of the Nilgiris hills in an extensive belt of forest (Neelakantan, 1988).

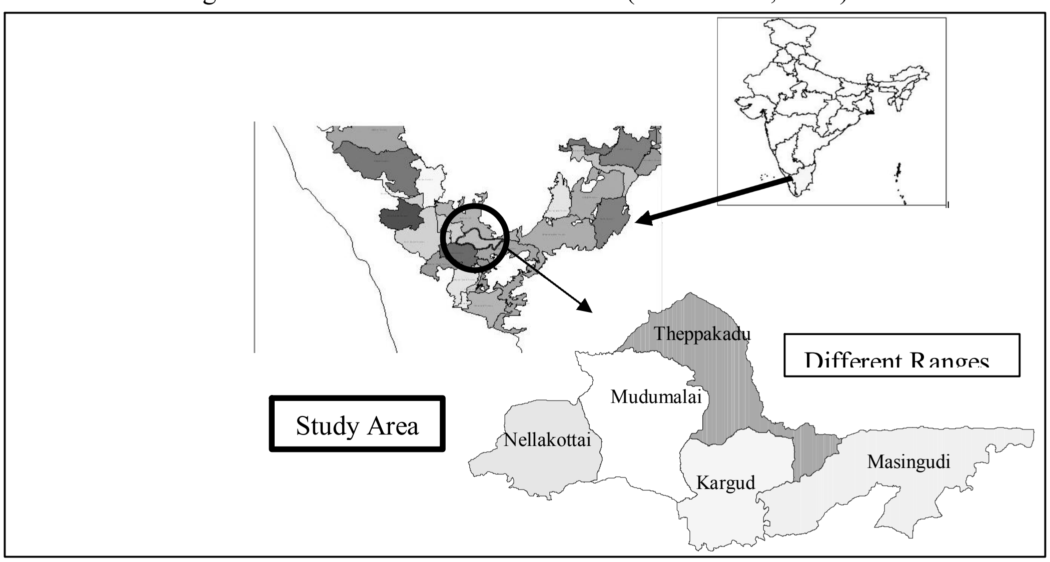


Figure 3. 1: Location Map

3.1.2. Geomorphology

The topography of the Sanctuary consists of undulating hilly terrain with characteristic distribution of plain valley area, the 'vayals' (marshlands) in the Northwestern area falling in Nilgiris Wynaad plateau. The Eastern tract around Masinagudi is with gentle undulating slopes, is an arid tract, and extends into the Segur plateau. The undulating tract of the Sanctuary gradually rises in the North to a low range of hills, which runs east west and forms interstate boundary between Kerala and Tamil Nadu. The average elevation of the tract is 1000 m. The lowest elevation is at the foot of Moyar waterfalls, which is 851 m. The highest peak in the Sanctuary is Morganbetta with an elevation of 1258 m (Tyagi, 1993).

3.1.2.1. Geology

The geology of the area is constituted mainly with unclassified gneisses. This forms the parent material or country rock. The stratigraphical succession of the area is as under:

Sub recent to recent	-	Laterite cappings and soils
Younger intrusives	-	Quartz veins, basic dykes, pegmatites, granite and granite gneiss
		Pyroxenite and Charnockite
Archean	-	Basic granulite, Unclassified gneisses
		Banded micaceous and ferruginous quartzite

3.1.2.2. Soils

The report of the All India Soil and Land Use Survey carried out by the Central Soil Conservation Board includes the Nilgiris district (jurisdiction district of the study area) in the Red and Laterite Soil Region II. It classifies the soil of the plateau as Ootacamund Soil series. The soil is derived mainly from igneous and metamorphic rocks. In Mudumalai Sanctuary, the soil can be broadly classified as under:

- Black sandy loam containing over 50% sand and gravel
- Red heavy loam soil

3.1.2.3. Drainage

The general undulating terrain does not form any range of hills, which forms the watershed dividing line. Only, the low range of hills running east west on the boundary between Tamil Nadu and Kerala forms the watershed boundary. The central portion of the Sanctuary is somewhat elevated and slopes towards North East and West. Important streams in the Sanctuary include:

- Moyar in the southeastern part
- Biderhalla in the southern part
- Benne hole in the western part
- Doddagatti halla in the northern part
- Imberhalla in the central part
- Kakkanallah forms the frontier with Karnataka
- Avarhalla in the eastern part
- Segur River forms boundary with adjoining division

The general drainage pattern shows a till towards eastern side of the century. All streams flow into the Moyar River (Neelkantan, 1988; Tyagi, 1993). The water flowing in the Moyar River beyond Theppakadu suddenly falls into a deep gorge known as Moyar Gorge (Fig 3.2).

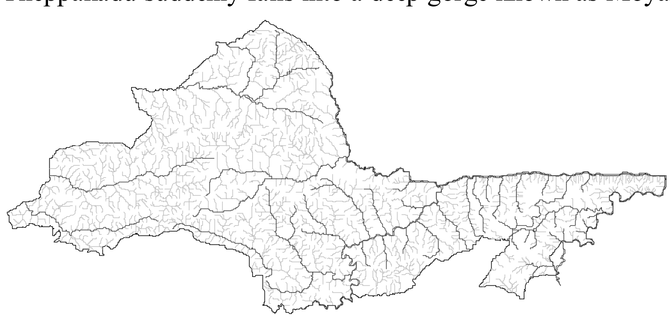


Figure 3. 2: Drainage Map

3.1.3. Climate

The climate is generally equable and moderate in the Sanctuary. The variation in aspect and precipitation causes a variable climate with distinct dry, wet and cold season. The wet season starts with the monsoon showers in June and continues until November. The Sanctuary receives both the southwest and northeast monsoon. The cold season begins in November and lasts up to beginning of February. The hot season starts from the middle of February (Neelkantan, 1988; Tyagi, 1993).

3.1.3.1. Temperature

The maximum temperature fluctuates between 29°c to 33°c and minimum temperature from 14°c to 17°c. The hottest months are from February to April and the coldest months are from December to January. The relative humidity is higher in the western portion and low in the eastern portion.

3.1.3.2. Precipitation

The Sanctuary receives both the southwest and northeast monsoon. The southwest monsoon is more active and sets in by June, and lasts up to September. Northeast monsoon lasts until November. The area also receives pre-monsoon showers from April to May. The western and southern part receives greater rainfall than eastern and northern parts of the Sanctuary. The intensity of rainfall decreases from south to north and from west to east. The variation in precipitation over short limits causes precipitation variation and luxuriance of vegetative growth in the area. The annual rainfall varies from 250 cms in the western part to about 40 cms in the eastern part. The major parts of the Sanctuary receives between 80 cms to 200 cms is rainfall (Neelkantan, 1988; Tyagi, 1993).

3.1.3.3. Frost

Frost is not common in the sanctuary except on the hill tops during winter.

3.1.3.4. Wind

The south west monsoon is accompanied by moderate velocity winds from the western side. The velocity of the winds is high at hill tops. Fire fighting becomes difficult due to the presence of wind.

3.1.4. Water management

Water is available uniformly for most part of the year. The water management in the sanctuary aims to distribute the water uniformly in the sanctuary so that it is available to the animals within their cruising distance. The water holes retain water for most part of the year except extreme summer season. There are several small and medium streams with perennial flow of water. Some streams tend to dry up during the summer season but in the valley, water is available in the artificial lakes and check dams. The north-western area and eastern part of the sanctuary experiences scarcity of water during extreme summer. Continuous flow of water in the power channel in northerly direction mitigates the water scarcity in the eastern part (Neelkantan, 1988; Tyagi, 1993).

3.1.4.1. Wetland and swamp

There are several swamps occurring in the valley of varying sizes. These are the low-lying depression at the foot of the hills. These provide ideal wallowing ground for herbivores. In the rainy season, water inundates these swamps. The swamp hydrology has changed during the years. During summer, we see small pools. These dry up during Feb-March and parched soil is exposed (Neelkantan, 1988).

3.1.5. Vegetation

The natural vegetation of Mudumalai is representative of the Western Ghat vegetation. The wide range of climatic factors and their interaction reflect the diversity of the vegetation communities. The variation in the vegetation types along with the serial and transitional stages is very much pronounced (Fig 3.3). According to the Champion and Seth classification, the broad vegetation types are as under:

2A Southern tropical semi-evergreen forest

- West coast semi-evergreen forest ($2A/C_2$)

3B Southern Moist mixed deciduous forest

- Moist teak-bearing forest ($3B/C_1$)
- Southern moist mixed deciduous forest ($3B/C_2$)

5A Southern tropical dry deciduous forest

- Dry teak-bearing forest ($5A/C_1$)
- Southern dry mixed deciduous forest ($5A/C_3$)

6A Southern tropical thorn forest

- Southern thorn forest ($6A/C_1$)

2B Moist bamboo brakes ($2B/E_3$)

4E Tropical Riparian fringing forest ($4E/RS_1$)

Habitat types	**Total Sq. km**	**Percent**
Dry deciduous forest	9.0	2.80
Dry deciduous tall grass forest	64.0	19.94
Dry deciduous short grass forest	38.5	12.00
Dry mixed deciduous forest	72.0	22.43
Moist deciduous forest	57.0	17.76
Moist mixed deciduous forest (semi-evergreen)	33.0	10.28
Thorn forest	47.5	14.78
	321.0	

Table 3. 1: Extent of major vegetation types

(Source: Studies by BNHS & IIS)

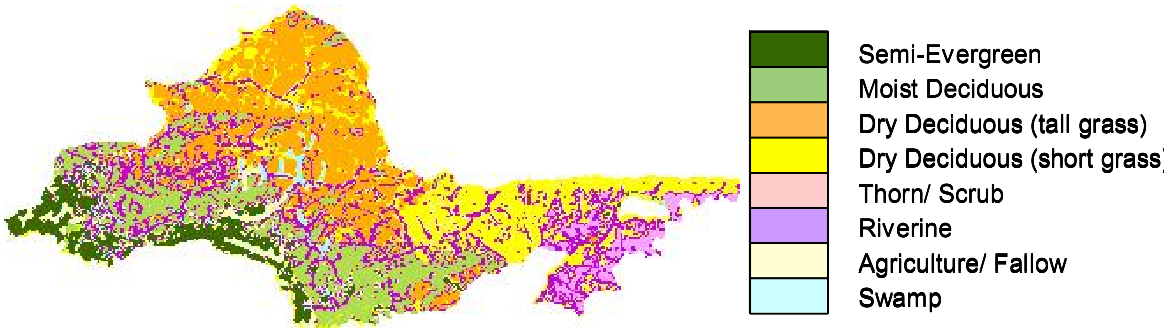


Figure 3. 3: Vegetation Map

(Source: ISRO & TN Forest department)

3.1.6. Wildlife

The semi evergreen forest in the western part with tall trees, climbers and lianas provides an excellent arboreal habitat. The moist and dry deciduous forest in the central part has tall trees. The grass growth in these deciduous forest with bamboos interspersed provides an ideal habitat for the animals. The interspersion of blank patches, swamps/edges create ideal habitat for animals. The deer population, especially sambar deer prefer moist deciduous forest during dry season and dry deciduous with tall grass during wet season (Varman & Sukumar, 1993). Chital deer prefer open patches when compared with the sambar deer.

The major fauna of the peninsular India represented in the Sanctuary include:

Primates	-	bonnet macaque, common langur
Cats & Civets	-	tiger, leopard, jungle cat, small indian civet
Canids	-	wild dog, jackal
Proboscids	-	elephant
Bovids	-	gaur (bison)
Cervids (deer)	-	chital, sambar, barking deer
Mongoose	-	common mongoose, striped napped mongoose
Rodents	-	giant squirrel, flying squirrel, black napped hare
Others	-	sloth bear, otter, wild boar, porcupine, striped hyena, mouse deer
Reptiles	-	marsh crocodile, monitor lizards
Avifauna	-	terrestrial and wetland birds

3.2. Justification for the selection of the study area

The choice for study on forest fire in Mudumalai wildlife sanctuary was not accidental. Fire is one of the most widespread and critical disturbance in most of the Protected Areas in India. It affects both flora and fauna of the ecosystem. The incidence of forest fires is on the increase and has detrimental effect on the PA conservation measures. We have always looked at the problem from the piece-meal approach. Often, we lack the scientific focus/ technical resources or sometimes the opportune area for study. In this context, Mudumalai wildlife sanctuary happens to be the right area for conducting the study because of its conservation significance and past management practices.

Mudumalai wildlife sanctuary constitutes an excellent habitat for the endangered species of wildlife in South India. This sanctuary is exceptional for the habitat diversity and the juxtaposition and interspersion of the various habitat factors. The diverse habitat types include semi evergreen, moist deciduous, dry deciduous, thorny open scrub, swamps and dry grasslands. These diverse habitats harbour a variety of flora and fauna. It has also great cultural significance in the local tribal communities. In view of all these significances, Mudumalai wildlife sanctuary has great scientific, educational and recreational values. The current landscape is testimony to the ever-changing social and economic interactions between forest growth and human use of these resources. The increased use of forests and rapid changes in the land cover has led to increased susceptibility of forests to recurrent fires (Kodandapani et al, 2004). Dry deciduous forests have several characteristics which make them susceptible to fire. This mainly includes accumulation of leaf litter, fairly open canopy which promotes grass growth and long dry season (Johnsingh, 1986).

3.3. Socio - Economic Structure

Livestock grazing, a major biotic interference originates from the peripheral villages on the Eastern and South Eastern fringes of the sanctuary.

3.3.1. Demography & Occupation pattern

As per Silori & Mishra (2001), there are 1475 families with a human population of about 7400. Of the total families, 22% belonged to the original tribal inhabitants viz. Irulas and Kurumbas (Table 3.2). However, with the establishment of hydro-electric projects, large number of landless labourers dominated the population in later years.

Village	Area (ha)	Families	Male	Female	Total	Average
Masinagudi	502.97	768	2079	1845	3924	5.1
Moyar	162.24	207	595	517	1112	5.4
Singara	777.11	115	300	267	567	4.9
Bokkapuram	601.03	193	451	425	876	4.5
Mavinhalla	214.32	101	266	232	498	4.9
Chemmanatham	48.95	12	21	21	42	3.5
Vazhaithottam	178.63	79	183	199	382	4.8
Total	**2485.24**	**1475**	**3895**	**3506**	**7401**	**5.0**

Table 3. 2: Demographic details of villages in Mudumalai Sanctuary

(Source: Silori & Mishra, 2001)

Daily wages for labour in hydro-electric projects, agriculture on marginal lands, Govt and self-employment form the major source of livelihood and occupation pattern in the study area (Table 3.3).

Village	Number of families under different occupation categories					
	Agricult	Labour	Self-Employ	Govt-Employ	NTFP Collection	Total
Masinagudi	46	425	129	135	33	768
Moyar	42	58	17	90	0	207
Singara	0	28	9	78	0	115
Bokkapuram	101	68	6	16	2	193
Mavinhalla	55	24	6	15	1	101
Chemmanatham	0	10	0	0	2	12
Vazhaithottam	20	39	8	11	1	79
Total	**264**	**652**	**175**	**345**	**39**	**1475**
Percent	**18%**	**44%**	**12%**	**23%**	**3%**	**100%**

Table 3. 3: Occupation pattern in the villages in Mudumalai Sanctuary

(Source: Silori & Mishra, 2001)

3.3.2. Livestock Grazing

Livestock rearing is the major economic activity for the landless labourers. Nearly 43% of the family population owns livestock, and that these amount to 9280 animals (Table 3.4).

Village	Owners	Cows	Bull	Buffalos	Sheep	Goat	Total
Masinagudi	309	2439	122	95	312	289	3257
Moyar	104	1661	51	132	113	29	1986
Singara	38	209	0	0	0	12	221
Bokkapuram	98	825	70	196	41	252	1384
Mavinhalla	40	808	33	0	72	123	1036
Chemmanatham	7	340	25	0	0	0	365
Vazhaithottam	34	966	33	0	3	31	1033
Total	**630**	**7248**	**334**	**423**	**541**	**736**	**9282**
Percent		**78%**	**3.5%**	**4.5%**	**6%**	**8%**	**100%**

Table 3. 4: Livestock population details in Mudumalai Sanctuary

(Source: Silori & Mishra, 2001)

3.4. Past working and management practices

The history of these forests and the planning initiation undertaken can be described in three phases.

3.4.1. Early period or pre-working plan period (before 1903)

The Mudumalai forests, of about 200 sq miles, were the property of the Tirumalpad of Nilambur. During the first half of the 19th century, it was leased out to a timber merchant, who on payment of a stump fee exploited the more accessible portions of the forests for many years. Captain Campbell of the Madras Engineers took Mudumalai forests on lease in 1856 for lumber extraction. As per the report of Mr Beddome, Conservator of forests, the Government entered on a 99 years lease with the Tirumalpad, in 1863. The Government worked the forests and attempted to raise teak plantations (1864-65). In 1884, Mr. Gamble drew up a scheme providing for annual working of different compartments, felling by silvicultural methods, rigid fire protection in certain areas and regulation of grazing. The Mudumalai forests were declared as reserved land under section 26 of the Forest Act. In 1887, Arbuthnot wrote working plan for Mudumalai and Benne forests, and on his suggestions, the forests were opened for sleeper fellings between 1898 and 1902 (Neelkantan, 1988; Tyagi, 1993).

3.4.2. The working plan period from 1903 to 1976

In 1907, Jackson's plan attempted to localize the random fellings that were taking place by dividing the forests into four forest blocks. Under Cox's plan in 1910, permanent demarcations with local names were given to the block lines. In 1914, proceedings for the acquisition of the forests from the owner were initiated. In 1927, they area was declared as a Reserve forest. C.R.Ranganathan’s plan from 1934-48 provided for selection felling, raising of teak plantations, maintenance of number of fire lines and employment of fire patrols during the fire season. An area of about 23 sq. miles of the forest was declared as a wildlife sanctuary. Jeyadev’s plan from 1954 to 1964 stressed on the wildlife management. The management of the Sanctuary and needs of the tourism received special and concentrated attention. The Sanctuary and was expanded in 1958 to an area of 318.70 sq kms. Thiagrajan’s plan from 1965 to 1975 provided for raising of teak plantations, thinning of previous teak plantations, and selection felling and marketing of various timber species. Due to wildlife damage, most of the teak plantations were discontinued after 1974. Jayaraman’s plan from 1976 to 1985 followed the same prescriptions as Thiagrajan’s plan (Neelkantan, 1988; Tyagi, 1993).

3.4.3. The management plan period from 1977 onwards

The first plan for Mudumalai Sanctuary was written by John Joseph from 1978-88. Intensive wildlife management practices were prescribed and implemented for forestry management. The selection felling and marketing working circle, minor forest produce and teak plantation-working circle were under operation. Zonation of the sanctuary area into various management zones included as under:

- Wilderness zone
- Optimum / integrated forestry zone
- Intensive development or tourism zone
- Administrative zone
- Buffer zone
- Experimental zone

The wildlife management practices included protection and habitat improvement activities. Fire protection received importance from the perspective of wildlife management. Subsequent plan by Neelakantan for the period 1988-93 focussed more on the wildlife management perspective.

3.5. Data Collection

The holistic understanding of the complex mechanism that envisages spatial and temporal dynamics requires synergetic approach. The data requirement therefore is of both spatial and non-spatial nature and also of various time scales. The combination of satellite remote sensing data and integrative tools such as GIS is an important complimentary system to ground based studies (Murthy et al, 2003).

In this study, the data collection envisaged collection of both spatial as well as non-spatial data from the different agencies (Govt and Non-Govt). It included base data information as well as relevant digital information. The base map on 1:50,000 scale was prepared in accordance to the Survey of India topographic sheet nos 58A/6 and 58A/10. We acquired spatial and non-spatial information on 1:50000 scale as per the prepared base map.

3.5.1. Spatial data

The spatial data collection envisaged the procurement of satellite imagery from the National Remote Sensing Agency (NRSA), Hyderabad. The Indian Remote Sensing Satellites (IRS) - 1C/1D & P6 LISS 3 (Linear Imaging Self-Scanning Sensor) MSS (Multi Spectral Scanner) data were procured from NRSA, Hyderabad (Table 3.6). The orbital characteristic of the IRS satellites is given in Table 3.5.

The LISS 1 data, of earlier years, available with the Tamilnadu Forest department & Indian Space Research Organization (ISRO), Bangalore, were also procured.

The data procured for the fire and non-fire season is as under:

For non fire season - 8^{th} Dec 2000

For fire season - 6^{th} Mar 2000, 18^{th} Mar 01, 24^{th} Feb 02, 13^{th} Mar 03, 22^{nd} Mar 04 & 4^{th} Mar 2005

This data has been procured as a digital product.

Besides, data for the fire season were collected from the ISRO and Tamilnadu Forest department for the fire season of earlier years as under:

Satellite & sensor - IRS 1A/ 1B LISS-I MSS data

For non fire season – Jan 1991

For fire season - Mar 1991, Mar 1992, Apr 1993, Mar 1994 & Mar 1995

The data of earlier years (1991-95) has been collected in the form of hard copy.

Satellite Name	Sensor	Type	No. of Bands	Spectral Range (microns)	Resolution (metres)	Swath Width (km)	Revisit Time (days)
IRS-1A & IRS-1B	LISS-I	MSS	4	0.45-0.52 (B) 0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	72.5	148	22
IRS-1C	LISS-III	MSS	4	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR) 1.55-1.70 (SWIR)	23.5 70.5	141 148	24
IRS-1D	LISS-III	MSS	4	0.45-0.52 (B) 0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	23.5 70.5	142 148	22
IRS-P6	LISS-III	MSS	4	As in IRS-1C	23.5	141	24

Table 3. 5: Orbital characteristics of IRS series satellite

(Source: Website of NRSA, Hyderabad)

Satellite	Sensor	Path	Row	Data type	Quad-No	Lat	Long	Date of pass	Rows (Pixel)	Cols (Scan)
IRS-1D	LISS3	99	65	BIL	58A10 58A6	$11^0$31' $11^0$42'	$76^0$21' $76^0$45'	08-12-2000	2897	3059
IRS-1C	do	do	do	do	do	do	do	06-03-2000	3156	3003
IRS-1D	do	do	do	do	do	do	do	18-03-2001	2977	3039
IRS-1C	do	do	do	do	do	do	do	24-02-2002	3160	3002
IRS-1D	do	do	do	do	do	do	do	13-03-2003	3016	3030
IRS-P6	do	do	do	do	do	do	do	22-03-2004	2961	2968
IRS-P6	do	do	do	do	do	do	do	04-03-2005	2960	2968

Table 3. 6: Details of the satellite data procured from NRSA

The main sources of primary data collection were from Tamilnadu Forest. Following information on 1:50000 scale on the base map was collected:

- Administrative boundary of the Division & Ranges
- Demarcation of Beats (smallest administrative unit) & Compartments (smallest management unit)
- Major Road network in the study area
- Major drainage system
- Location of Perennial & Non-perennial Water bodies
- Location of Enclaves (Enclosures), adjoining Estates and peripheral Villages
- Tourism Zone & Grazing zone
- Transect layout map for wildlife census

- Location of Fire lines, Fire watchtowers & Fire camps
- Location of poaching incidences

3.5.2. Non-spatial data

The non-spatial data collected pertained to the objective of the study and related information of the procured spatial data. The following details were obtained from the Tamilnadu Forest department:

- Wildlife Census Report of Large Mammals for 1999, 2002, 2004 & 2005 including raw census data set
- Tourism details from 2000-2005
- Details of Poaching incidences from 1991-2005
- Grazing offences for last 5 years
- Demographic & Livestock details of the adjoining major villages
- Details of Non-Timber Forest Produce (NTFP) offences for last 5 years
- Fire Reports from 1991-2005
- Expenditure details on Fire Protection measures for last 5 years
- Average monthly meteorological data for last 10 years

3.6. Field Visit

The field visit was primarily aimed at establishing the ground truth/ verification. The aspects covered during the field visit included:

- Marking of the various habitats and forest types
- Distribution pattern of the major mammals especially ungulates in different habitats
- Operation of Eco-Tourism in the tourism zone
- Location of Enclaves and Villages including grazing pressure
- Facilities and Location of the Anti-poaching/ Fire camps & Watchtowers
- Ecological, Economic, Social & Recreational values of the Park

3.7. Summary

Mudumalai Wildlife Sanctuary happens to be the hotspot from the perspective of biodiversity conservation. The Protected Area faces one of the most critical disturbance i.e. forest fire which needs to be ameliorated. Past history and management practices do reflect on the various fire protection measures. The area offers an excellent site for undertaking this study. The spatial and non-spatial information along with ground truth data collected from the area have a direct relevance on developing likelihood/ evaluation models. It will help in planning an appropriate mitigation strategy as well as developing a customized output for the mitigation strategy.

4. Materials & Methods

This chapter provides an approach to various materials and methods required for the project. It details the processing and standardization of the data. The chapter highlights the approach to the identification of various causative factors including major and critical factors responsible for fire occurrence. It also spells out the different anti-causative agents. It gives the approach to the designing of the fire likelihood model with data requirements and standardization of various parameters. Similarly, it provides data needed and standardization of parameters for the evaluation models pertaining to the area value and mitigation strategy. Finally, the chapter gives the structural design for GIS customization for easy perception.

4.1. Introduction

To carry out the study the following research methodology is proposed:

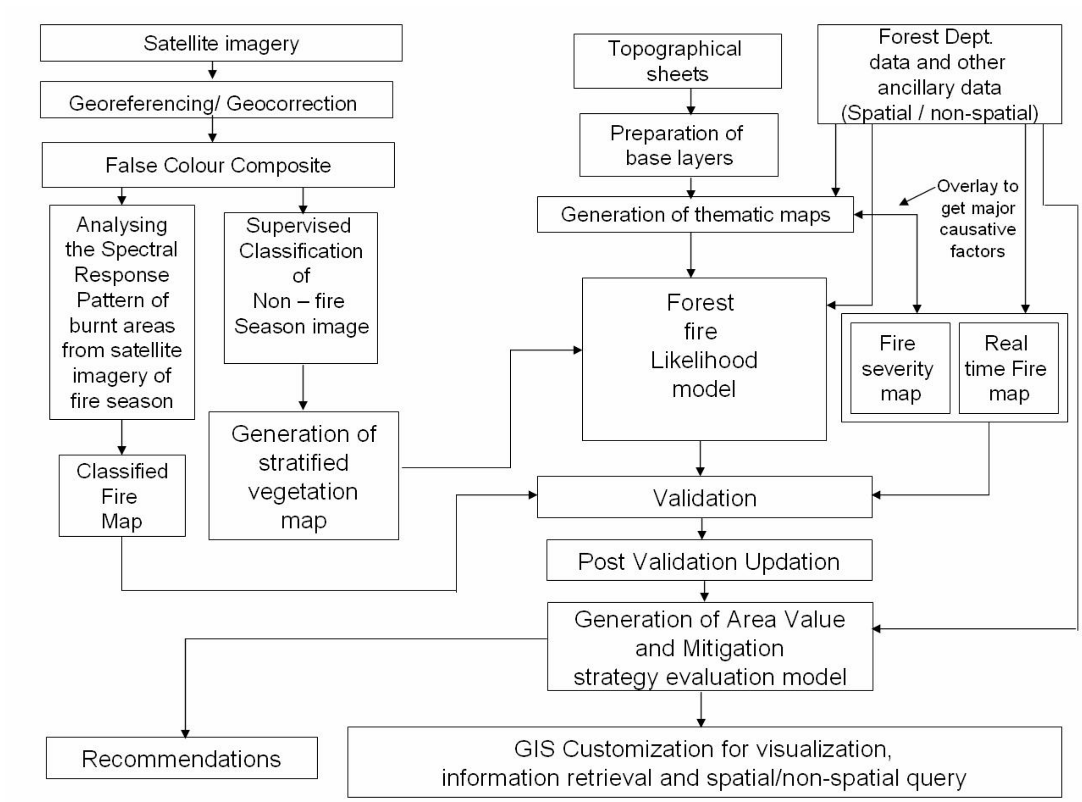


Figure 4. 1: A diagrammatic representation of the methodology

4.2. Pre-processing of the data

4.2.1. Geo-referencing /Geo-correction

Raw digital images contain geometric distortions making them unsuitable for use as map base. The intent of is to compensate for the various distortions caused by different factors for achieving highest practical geometric integrity (Lillesand & Kiefer, 2000). Random and systematic distortions are corrected by analysing distributed Ground Control Points (GCPs). The values are subjected to least square regression analysis to determine coefficient for two coordinate transformation equations. Resampling is carried out to determine the pixel values for the output matrix from the original image matrix by the nearest neighbour approach.

It is essential for GIS and spatial analysis that all the data are brought to one coordinate system (Burrough & McDonnell, 1998). There are three main ways of projecting locations from an ellipsoid onto a plane surface viz. cylindrical, azimuthal and conical projection. The best projection to use depends on the location of the site on earth's surface. In respect of the study area, Polyconic projection system with Everest ellipsoid and India-Bangladesh datum has been proposed.

4.3. Standardization of the data

Most of the administrative and thematic layers have been generated from the data obtained from the Tamilnadu Forest department. It becomes all the more important to bring such data at a uniform scale for any GIS and spatial analysis. In respect of the procured satellite image, the base map of Survey of India (SOI) has been used at a 1:50,000 scale. Therefore, the same scale has been used for the generation of various thematic layers.

Data collected is qualitative as well as quantitative in nature. Qualitative data is nominal whereas quantitative data is measured along an interval or ratio scale. In between qualitative and quantitative data, an ordinal scale of measurement exists (de By, 2004). For the purposes of this study, all the data are brought into following element of order – low, moderate, high and extreme. As per Bertin's visual variables, colour has been used to represent these different categories.

4.4. Data Processing

4.4.1. Classification of satellite imagery

Supervised classification of the imagery has been carried out for the two season images:

- Non-season
- Fire season

The non-fire season imagery is used mainly to get the major forest types. The fire season image has been used for the delineation of the affected areas. Visual classification is carried out for the burnt areas.

4.4.1.1. Spectral Response of Burnt Areas

The forest vegetation reflects more strongly in the infra-red portion of the electro-magnetic spectrum (Lillesand & Kiefer, 2000). As a consequence of fire, the scorched area shows considerable reduction of reflectance because of carbonization and appears black in color in false color composite (fig 4.2). Digitization of the burnt areas has been carried out for approx. 10 years for validation purposes.

4.4.1.2. Generation of stratified vegetation map from classified map

A combination of multi-spectral thresholding and supervised classification using ground information from the details obtained from the Forest department has been utilized to delineate major vegetation types. For ground truth, GPS locations and an existing map of the forest department has been used. The stratification of the vegetation into broad classes has been done from the perspective of flammable habitat (fig 4.3).

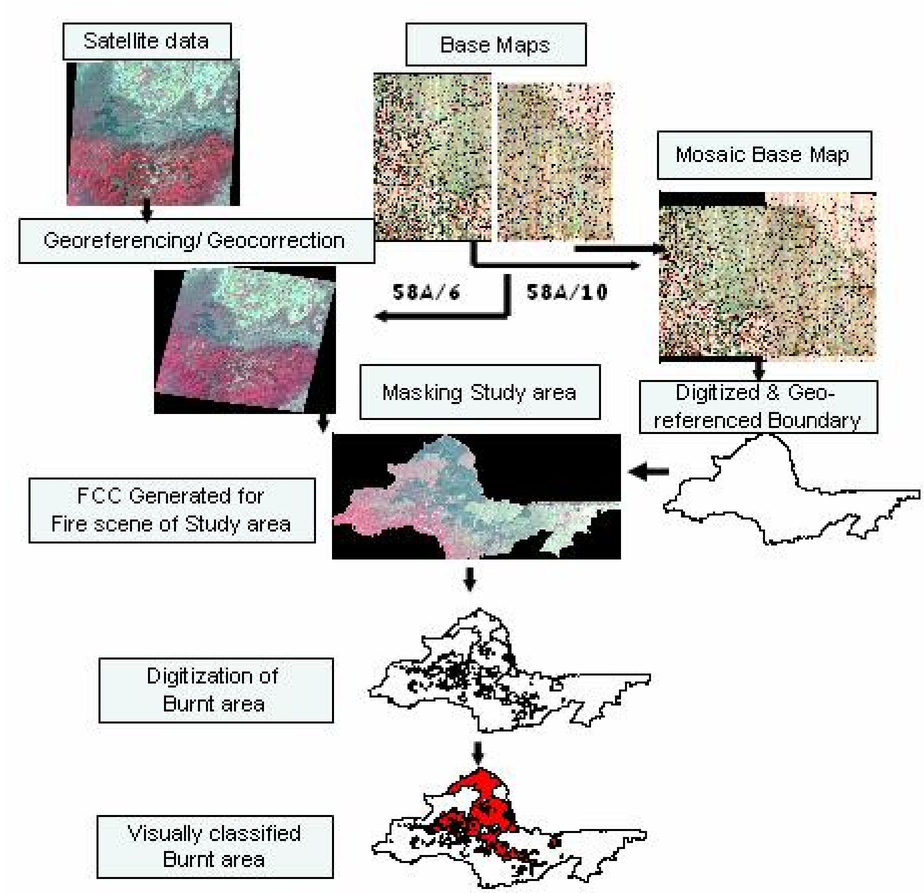


Figure 4. 2: Visual classification & digitization of burnt area

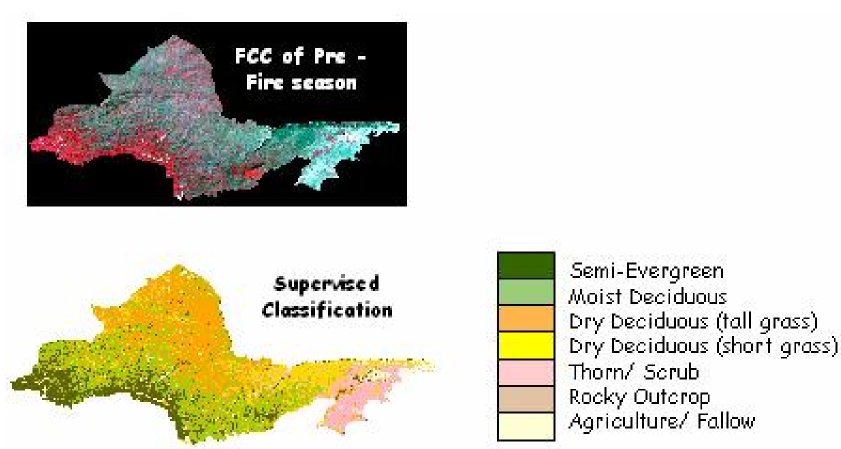


Figure 4. 3: Classification of major Vegetation types

4.4.2. Post Classification smoothing

The raster data is converted into vector format for using the same data format in the likelihood model. A median filter has been used to erase fine details and retain larger regions with the same brightness value for getting broad habitat classes (Jensen, 1996).

4.4.3. Classification Accuracy Assessment

The classification accuracy assessment is necessary for obtaining locational accuracy (Jensen, 1996). The two sources of information viz. remote-sensing derived classification map and reference test information has been compared. Ground truth data & map available with the forest department has been considered for the reference set. The relationship between the two sets of information has been summarized in the *error matrix*. An error matrix represents accuracy more effectively with both errors of inclusion (commission error) and errors of exclusion (omission errors). *Overall accuracy* is computed by dividing the total number of correctly classified pixels by total number of reference pixels. A *producer's accuracy* is determined by dividing the total number of correct pixels in a category by the total number of pixels of that category in the reference data (column total). This is also a measure of omission error. The *user's accuracy* is computed by dividing the total number of correct pixels in the category by the total number of pixels actually classified in that category. This is a measure of commission error (Jensen, 1996; Lillesand & Kiefer, 2000).

KAPPA analysis, which is a discrete multivariate technique, is also used for accuracy assessment. Even a completely random assignment of pixels to classes produces percentage correct values in the error matrix (Lillesand & Kiefer, 2000). The K_{hat} statistic is the measure of the difference between the actual agreement between reference data and an automated classifier and the chance agreement between the reference data and a random classifier. The K_{hat} statistic is computed as

$$K_{hat} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i}}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

where r is the number of rows in the matrix

x_{ii} is the number of observations in row i column i

x_{i+} and x_{+i} are the marginal totals for row i and column i respectively

N is the total number of observations

The accuracy and KAPPA statistic has been computed for the broad habitat types in respect of the study area.

4.5. Generation of Base Layers

The base layers are generated at a 1:50,000 scale on SOI topo-sheet for the study area as per the details collected from the Tamilnadu Forest department. Vector layers in the form of points, line and polygons have been prepared by digitization. Layers have been generated for various administrative and management units/features. The following layers have been generated as under:

4.5.1. Spatial data showing Administrative units

Figure 4. 4: Digitization of Administrative and Management units

Beat boundary forms the basic administrative unit. Compartment forms the management unit which is based on ecological and natural features. Compartment boundary is generally considered for delineation and extrapolation for any sampled area.

4.5.2. Spatial data showing Roads & Drainage

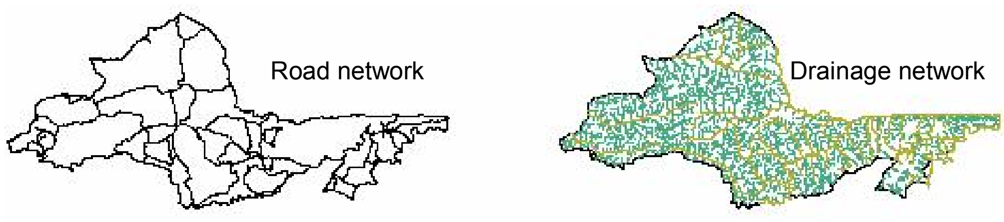


Figure 4. 5: Digitization of Road and Drainage network

The road and drainage network are important from the perspective of planning mitigation strategy.

4.5.3. Spatial inputs for Causative factors

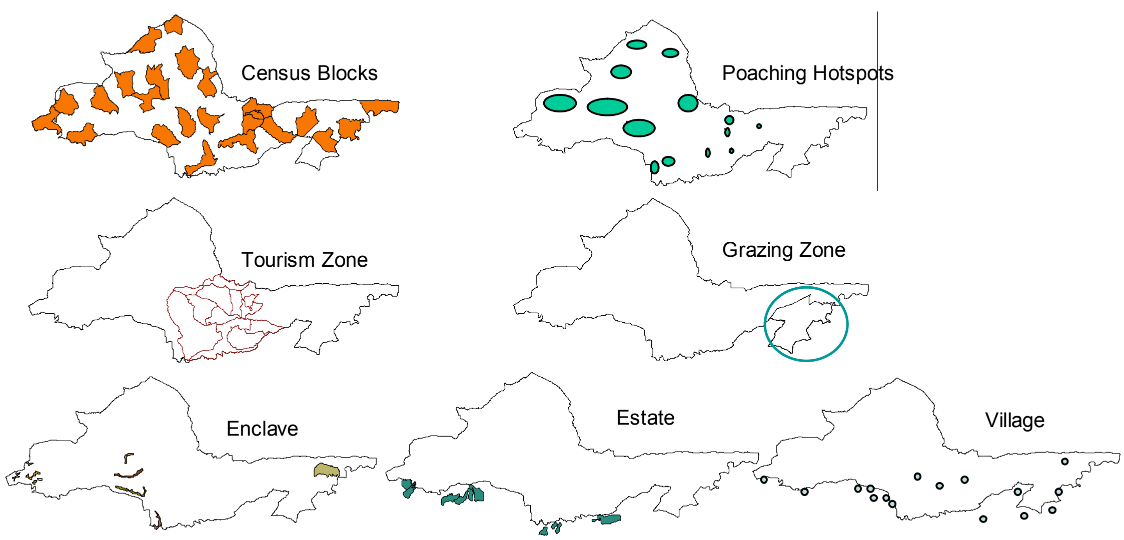


Figure 4. 6: Digitization of Causative factors

The above inputs have been used for the purpose of identification and quantification of various factors leading to forest fire in the study area.

4.5.4. Spatial inputs for Anti-causative factors

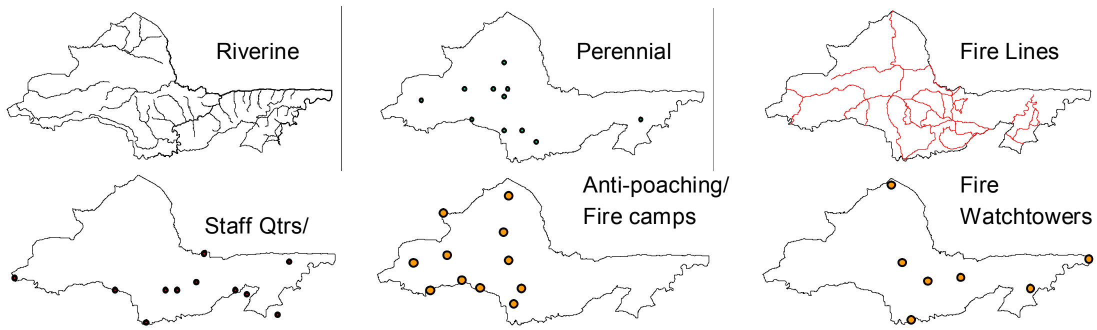


Figure 4. 7: Digitization of Anti-causative factors

The above inputs have been used for seeing the effect on forest fire likelihood when various anti-causative agents become operational and to what extent, they are effective.

4.6. Identification and quantification of causative & anti-causative agents

4.6.1. Possible Causative factors

Literature review, management plans of the past and current years along with fire reports help in establishing the possible causative factors prevailing in the area. Of the possible natural and man-made causes, the study area faces fire primarily due to the following major reasons:

- Antler Collection
- Poaching (mainly for ivory)
- Uncontrolled Tourism
- Livestock Grazing
- Enclaves & Settlements
- Adjoining Estates
- Peripheral Villages

4.6.2. Major causative factors

The thematic maps in context of major causative factors have been generated with the dataset collected from the field/forest department. The raw data has been considered in the computation of certain causative factors like antler collection and poaching. Whereas, in respect of other factors, multiple buffer has been created around the available area for that factor and same has been delineated into four categories of low, moderate, high and extreme.

4.6.2.1. Antler Collection

Stags of both Chital (*Axis axis*) and Sambar deer (*Cervus unicolor*), which are found in the study area, have antlers. They shed their antlers periodically to get rid of excess intake of calcium (Prater, 1971). The shedding in South India is usually in Aug-Sept. Illicit antler collectors clear the ground with fire during the dry season of Feb-Mar for easing picking (Johnsingh, 1986). The computation of deer density becomes significant as the antlers are borne only in the males and are shed annually. The sex-ratio is distributed uniformly 1:1 in the study area hence, the classification of deer density as per wildlife census data of 2002, 2004 and 2005 has been categorized as under:

Low:	< 15/km^2	Moderate:	15 – 30/ km^2
High:	30 – 45/ km^2	Extreme:	> 45/km^2

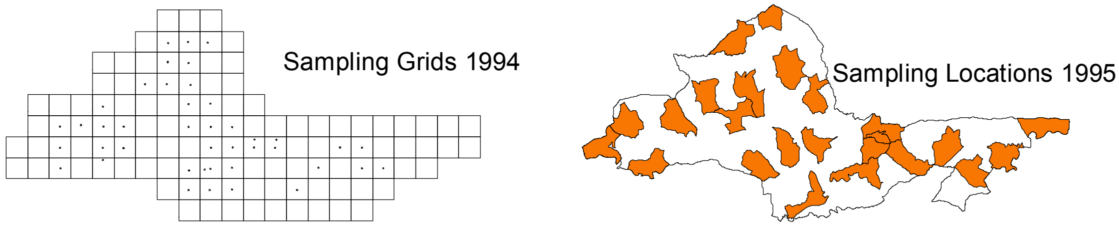


Figure 4. 8: Layout of sampling grids and sampling locations

Animal density has been computed as per sampling grids and blocks following Line Transect method (King's Census method). Data analysis involves conversion of angular sighting distance into perpendicular sighting distance required for density calculation using the following formula (Rodgers, 1991):

$$D = \frac{n}{t * 2w} \qquad (w = r * \sin\theta)$$

Where D = density (Number of animals/ sq. km)

n = total number of animals seen

t = length of line transect

2 = for both sides of the transect

w = perpendicular sighting distance

r = angular sighting distance

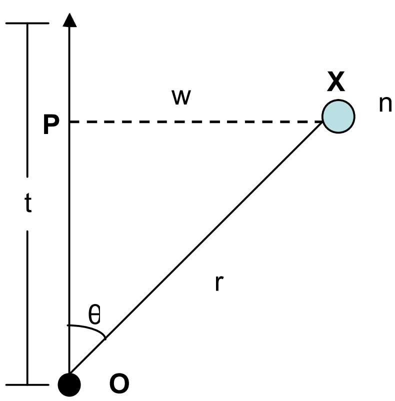


Figure 4. 9: Transect layout for density computation

As per the fig 4.9, the observations have been recorded by the observer (O) with details of bearing (θ) of animal at location (X) including its number. Data on angular sighting distances (r) for each species has been compiled from all transects within each stratum (compartment level) and a single mean angular sighting distance for each species has been calculated ("r"). Density of each species has been computed for that transect/s and extrapolation of the calculated density has been done at the compartment level (based on ecological/natural boundary).

4.6.2.2. Poaching

Poaching, mainly for ivory, is very prominent in the study area and ground is cleared for clear visibility and sighting of the targets. Computation of the data of the earlier recorded poaching has been carried out and sensitive compartments have been categorized as per the recorded offences.

The data available from 1991 to 2005 has been used in categorization of the sensitive compartments which could be referred as poaching hotspots. The categorization has been done as under:

Low:	Nil	Moderate:	1 incid./ compt
High:	2-3 incid. / compt	Extreme:	4 & more/ compt

4.6.2.3. Tourism

Tourism in the study area could be analyzed in two phases:

- prior to 1995
- after 1995

Before 1995, private vehicles were allowed in the tourism zone, whereas after 1995, only departmental vehicles were put into operation. The second phase could be considered as responsible for controlled tourism. Tourism zone basically is confined to the central portion of the study area. The only portion of the road left uncontrolled, is the State highway passing through the sanctuary area. Proximity analysis has been envisaged to delineate zone of influence. The multiple-buffer of 200m (on both sides of the road) has been generated around the tourism zone. This creates a new feature class or buffer features with the buffer distance.

4.6.2.4. Grazing

Study area is open for livestock grazing in one of the Reserved Forests, in the eastern portion, which is mainly scrub/thorn. An important issue in the grazing pressure is that, livestock is primarily meant for the collection of dung, which is used in the manufacture of manure. Hence, cattle are not stall fed and are left to graze freely inside the forest area. Due to the extreme livestock pressure as per the grazing offence report, illicit pressure extends beyond the area open for grazing. The cattle pressure in this area is nearly 9000 units (Silori & Mishra, 2001) and extends inside the forest area up to 5 km in a better habitat (as per grazing offence report). A multiple buffer of 1500 m (to account for illegal pressure) has been created around the grazing zone to account for the illicit grazing pressure.

4.6.2.5. Enclaves & Settlements

Towards the eastern extremity, the biggest enclave is that of Tamil Nadu Electricity Board (TNEB). In this enclave, pressure overlaps with the grazing pressure in the grazing zone. Inside the park, the enclaves are primarily in the swampy patches and the pressure is limited to scanty livestock population. A multiple buffer has been generated with 200 m distance as the zone of influence to account for the pressure. It is seen that pressure from the enclaves is confined in three distinct portions in three diverse habitats.

4.6.2.6. Adjoining Estates

The tea and coffee estates are primarily located on the southern side of the park and the pressure is exerted mainly in terms of boundary clearance. Estate laborers also exert pressure in terms of firewood and non-timber forest produce (NTFP) collection and very limited livestock. A multiple buffer has been generated to account for the zone of influence with a distance of 200m.

4.6.2.7. Peripheral Villages

The villages are mainly located on the southern and southeastern fringes. The pressure is mostly in terms of livestock pressure on the southeastern fringe villages and few instances of poaching of straying deer on the southern fringes. A multiple buffer of 500 m has been generated to account for the zone of influence.

4.6.3. Critical factor responsible for fire occurrence

For the identification of critical causative factor responsible for forest fire occurrence, it is necessary to first digitize the burnt areas and overlay the same to assess the potential of each causative factor.
Images have been procured for two phases.

- 1991 to 1995 and
- 2000 to 2005.

The images have been procured for two phases in order to see the effectiveness of causative as well as anti-causative factors. Tourism was controlled in the year 1995 and anti-poaching/fire camps were established in the year 2000.
The fire burnt area is categorized in four classes for different causative factors in order to ascertain the critical causative factor/s responsible for the forest fire occurrence. In the above delineated classes, 'nil' influence of the causative factor has been considered in the low category. There could be possible overlaps between different causative factors. The same is dependent on the distribution pattern/zone of influence of particular factor vis-à-vis habitat. Similarly, effectiveness of anti-causative factors can be evaluated in terms of burnt area falling in the second phase.

4.6.4. Anti-causative agents

The anti-causative agents in respect of the study area can be grouped into two categories:
Natural factors that include:

- forest/habitat type like riverine patches, semi-evergreen forests etc
- rocky outcrops
- perennial streams

Man-made anti-causative agents include:

- anti-poaching/fire camps
- fire watch towers
- fire lines
- staff quarters & check posts
- controlled tourism
- perennial check dams

4.6.4.1. Non flammable natural habitat

The above habitat is constituted by semi-evergreen patches on the southern side and rocky outcrop on the northwestern gorge area. The forest fire incidences are quite limited in such areas and are confined to the intermittent grassy swamps amidst the semi-evergreen forests and some grassy growth on the rocky outcrops.

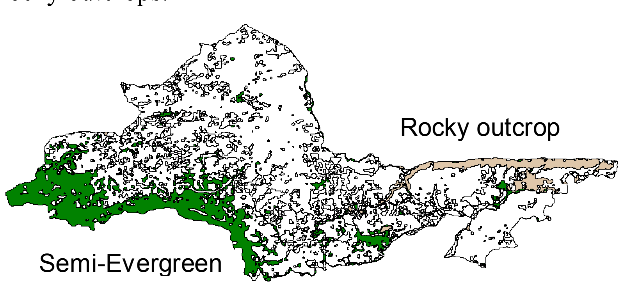


Figure 4. 10: Non-flammable habitat

Riverine patches are confined to the perennial and certain seasonal streams.

A multiple buffer of 20 m has been created to account for the zone of influence of the riverine vegetation in checking inflammability.

4.6.4.2. Anti-poaching/Fire camps

The anti-poaching/fire camps have been stationed in the study area since 1998 and the fire occurrences recorded between 2000 and 2005 could show the effectiveness of the camps. All these camps are manned with forest staff and tribal watchers who patrol the vicinity of the camp on a daily basis with a radius of up to 2-3 km. A multiple buffer of 500 m has been created to account for the patrolling distance. The vicinity is categorized into low, moderate, high and extreme pressures.

4.6.4.3. Fire Watch towers

Fire watch towers are erected primarily for fire detection. But the towers also have anti-causative effect to a limited distance as such towers are not manned by a regular team. A multiple buffer of 100 m distance has been generated to delineate the effectiveness zones. The conservative distance of 100 m has been considered for the watch towers, as the staff patrols from the anti-poaching/fire camps during the fire season and watch towers are visited sparingly.

4.6.4.4. Fire Lines

Fire lines are created to check the spread of fire. Mostly existing administrative and management boundaries (compartment lines) and road sides are cleared as fire lines. A multiple buffer of 10m distance has been generated to delineate the effectiveness zones.

4.6.4.5. Staff Quarters & Check posts

The location of staff quarters and check posts also acts as a deterrent for forest fire. Here again, the effective zone of influence is limited (within 1 km) as these establishments are also engaged in multifarious activities. A multiple buffer of 300 m has been generated to delineate the zone of influence.

4.6.4.6. Controlled Tourism

The ban on the operation of the private vehicles was imposed towards mid-1994. Only departmental vans are put to operation in the tourism zone. However, still, state highway passing through the protected area has no control on the vehicles passing and same imposes zone of influence. A multiple buffer of 200m distance has been delineated to categorize the zone of influence.

4.6.4.7. Perennial Check dams

Perennial check dams have water spread as well as moisture in the vicinity, which acts as a deterrent in the forest fire. A multi buffer of 50m around the check dams has been delineated to account for the zone of influence.

The burnt area for 2000-2005 has been considered for the overlay to assess the implications/effectiveness of anti-causative agents. The only difference in the anti-causative agents in the second phase data (2000-05) when compared with the first phase data (1991-95) is the ban on the operation of private vehicles in the tourism zone and stationing of anti-poaching /fire camps in the study area.

4.7. Designing of forest fire Likelihood model

A Forest Fire Likelihood model integrates both Causative as well as Anti-causative factors. The qualitative model has been developed with the OSIRIS software which uses the model framework GEOPS (Verwej, 2005). GEOPS has been developed as framework that can be used for a wide range of knowledge models. The GEOPS envisages the following domain description.

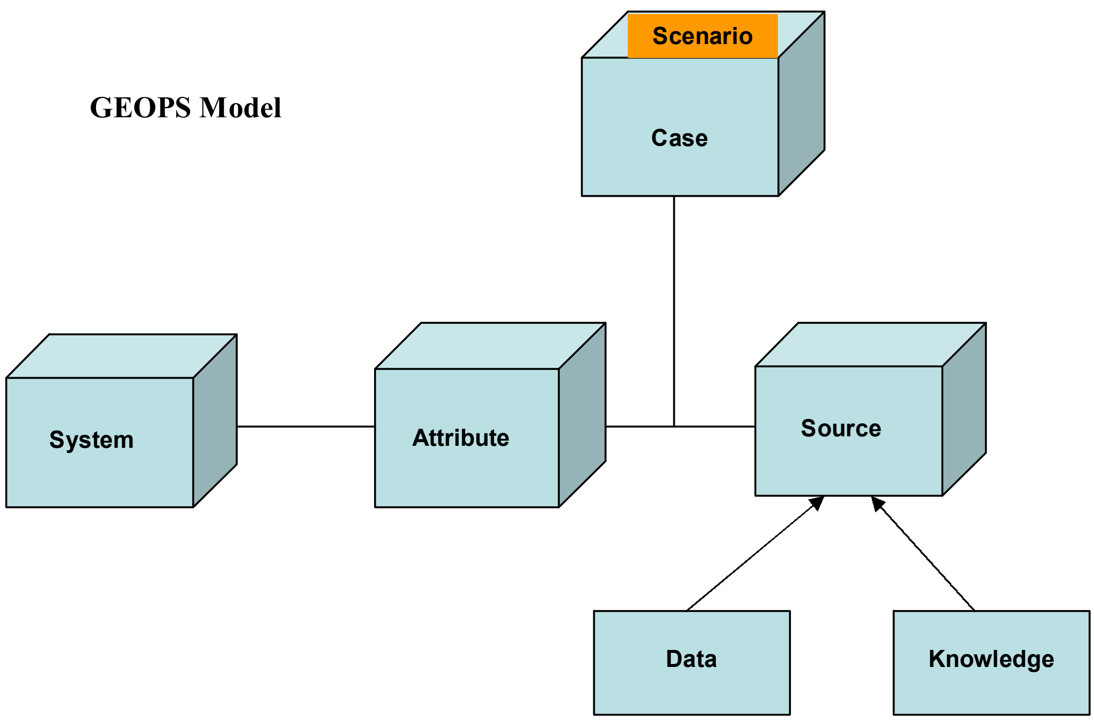


Figure 4. 11: Basic framework of GEOPS model

The basic concepts in the GEOPS domain model are as follows:
System – A whole consisting of entities, which have relationships.
Attribute – An entity
Source – Knowledge and (meta-) data that quantifies and/or qualifies a system.
Case – The whole of settings (system & source) used to calculate a specific situation.
Model – A usable form of knowledge.
Knowledge – Relation between sources that define a source operation.

- **System**

A domain is modeled as a system or a set of subsystems. Osiris consists of one system. The system describes the geographical space. In this study, Fire Likelihood can be viewed as a system and Causative & Anti-causative factors as sub-system. Even, Biotic Pressure can be modeled as a system with Demographic and Management factors as sub-systems.

- **System attribute**

One or more attributes can be ascribed to every system or subsystem. A demographic system has details on enclosure (enclaves) and exclosure (villages & estates). Similarly, Management dependent factors include grazing and tourism areas.

- **Source**

Two types of sources are used: data and knowledge. Knowledge and (meta-) data quantify and/or qualify a system. A source consists of a knowledge matrix, an ESRI Avenue script, an ESRI Grid, or a Decision tree. A source can be an ESRI grid with spatial use, or a knowledge matrix that translates spatial use to fire likelihood zones with colors varying between red and green. Data in the form of map layers and relational data base has been used. Knowledge describes the relation between various data sources and/or other knowledge sources. This knowledge has been used in 4x4 knowledge matrix.

- **Case**

A case is made of a set of connections between system attributes and sources. A case fixes the calculation scheme in which system attributes, are connected to sources, and necessary attributes of sources are connected to system attributes. This model is used for the calculation of each scenario. For example, in this study, we can supply the antler factor (attribute) of an animal distribution dependent (system) in the form of an antler distribution and habitat map (data source).

- **Scenario**

The contents of a case are described by these connections, but also by external parameters. This external control is described in a scenario which is part of the case. To calculate a scenario, we have to connect ESRI grid sources to the necessary attributes which are not yet connected. As soon as a system attribute has another source or an external parameter is changed, it is a new case. In the Fire Likelihood model, various scenarios can be generated to describe the best fit for fire likelihood.

4.7.1. Data Requirements

4.7.1.1. Generation of System Attributes for the Fire Likelihood model

The first step in the development of the Fire Likelihood model is the generation of System categories and attributes in the GEOPS based OSIRIS. This is further connected with the source using ESRI Grid and Knowledge Matrix.

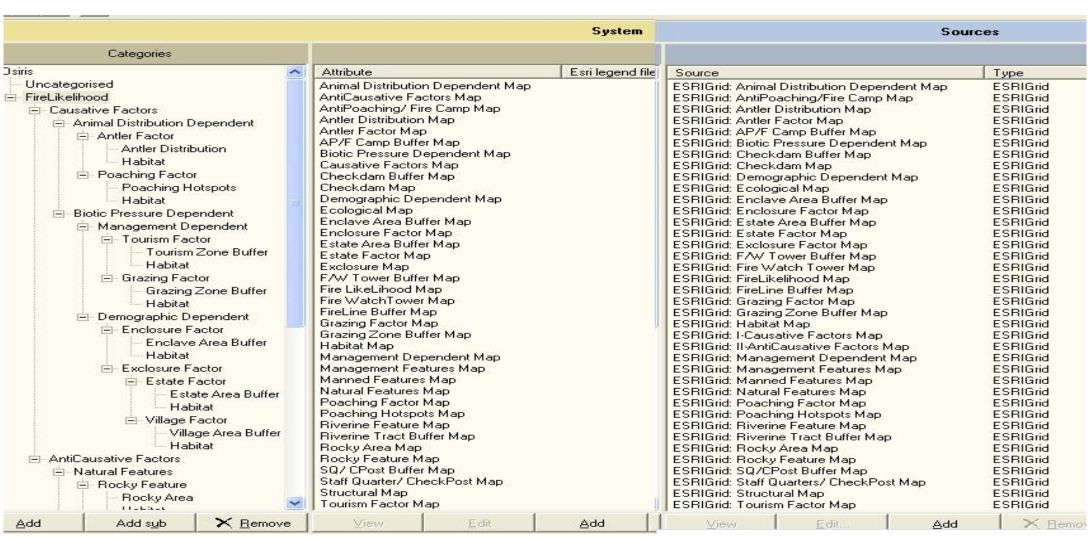


Figure 4. 12: System Attributes and Sources in the Fire Likelihood model for the study area

The following base maps generated are connected to the ESRI legend files in the system attributes:

Maps related to the causative factors

Antler distribution Map

Poaching hotspot (mainly for ivory) Map

Tourism zone buffer Map

Grazing zone buffer Map

Enclave area buffer Map

Estate area buffer Map

Village area buffer Map

Map related to flammability

Habitat Map

Maps related to anti-causative factors

Rocky area Map

Riverine tract buffer Map

Anti-poaching/fire camp buffer Map

Staff quarter/check post buffer Map

Fire line buffer Map

Fire watch tower buffer Map

Check dam buffer Map

A base cross map is used to generate the following causative & anti-causative factor maps as a result of use of Knowledge Matrix:

Causative Factor Maps

- Animal distribution dependent Maps
  - Antler factor Map
  - Poaching factor Map
- Management dependent Maps
  - Tourism factor Map
  - Grazing factor Map
- Demographic dependent Maps
  - Enclosure factor Map
  - Exclosure factor Map (Estate & Village factors)
- (Biotic pressure dependent includes Management & Demographic dependent)

Anti-causative Factor Maps

- Natural features Map
  - Rocky feature Map
  - Riverine feature Map
- Manned features Map
  - Anti-poaching/Fire camp Map
  - Staff Quarter/Check post Map
- Unmanned features Map
  - Ecological (Fire line) Map
  - Structural (Fire watch tower & Check dam) Map
- (Management feature includes both Manned & Unmanned features)

4.7.1.2. Case Dependency for Fire Likelihood model

Figure 4. 13: Flow diagram showing case dependency for Likelihood model

4.7.1.3. Development of Scenarios in Fire Likelihood model

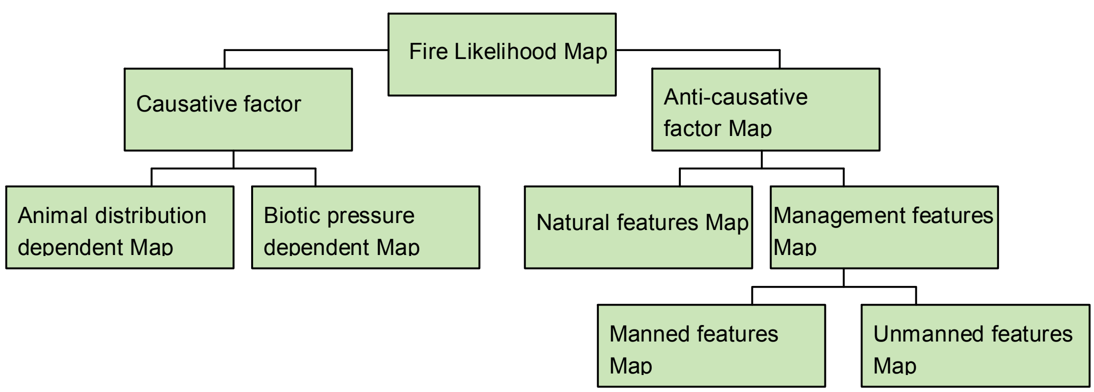


Figure 4. 14: Flow diagram showing Scenario for Likelihood model

4.7.2. Standardization of Parameters

For the purposes of this study, all the data are brought into the following categories – low, moderate, high and extreme.

4.8. Designing of Evaluation models

Area Value model is generated to establish the ecological, economic and social values of the study area. It becomes all the more important when we are devising the management strategy based on the forest fire likelihood model. Resources are extremely limited and the Area Value model helps in prioritizing the mitigation strategy. A qualitative model has been developed in OSIRIS, which uses the model framework GEOPS.

Mitigation strategy is formulated by the management interventions. These could be manned structures like anti-poaching/fire camps or unmanned features like fire lines etc. The current mitigation strategy is biased strongly towards areas getting burnt regularly. This has no bearing on the importance of that area in terms of area value or likelihood of any critical area getting burnt. The Mitigation strategy model so envisaged evaluates the existing mitigation strategy and suggests corrective measures. This is again based on the likelihood of an area getting burnt and value of that area. Based on the available infrastructure and funds, restructuring or redeployment of the management interventions is suggested. We can even have additions or deletions as per the model. This qualitative model like other models, has been developed in OSIRIS, which uses the model framework GEOPS.

4.8.1. Data Requirements for Area Value model

The Area Value model has been developed as a GEOPS model framework that can be used for a wide range of knowledge models.

4.8.1.1. Identification and Quantification of the Area Value

The **geomorphic value** of the area is mainly constituted by the drainage/catchment potential as well as natural rocky outcrop (gorge). The Knowledge Table (KT) for the catchment value is derived from the quantification of the drainage length and average width of the primary and secondary drainage with compartment as the base unit. KT for the gorge value is calculated from the extent of the rocky exposure. Both value maps are spatially overlaid with the flammable habitat map to limit the value to the fire likelihood areas.

The **biological value** is comprised of wetland and wildlife values. The wetland value is constituted by the extent of swampy areas as well as riverine areas. The wildlife value is calculated as per the distribution of the major mammals especially elephant, gaur, chital and sambar. The wildlife census data of 2002, 2004 and 2005 is taken to calculate the distribution of mammals and density classes have been considered for assigning ordinal values.

The **economic value** comprises of plantation (teak) and vegetation values. The plantation value has been quantified as per the stock (in ha.) of teak plantations in a particular compartment. Vegetation value has been accorded an ordinal value as per the habitat type from the wildlife perspective including plant species density in different habitats.

The **social value** comprises of grazing and recreational values which has been computed as per the available zonation.

4.8.1.2. Generation of System Attributes for the Area Value model

The first step in the development of the Area Value model is the generation of System categories and attributes in OSIRIS. This is further connected with the source using ESRI Grid and the Knowledge Matrix.

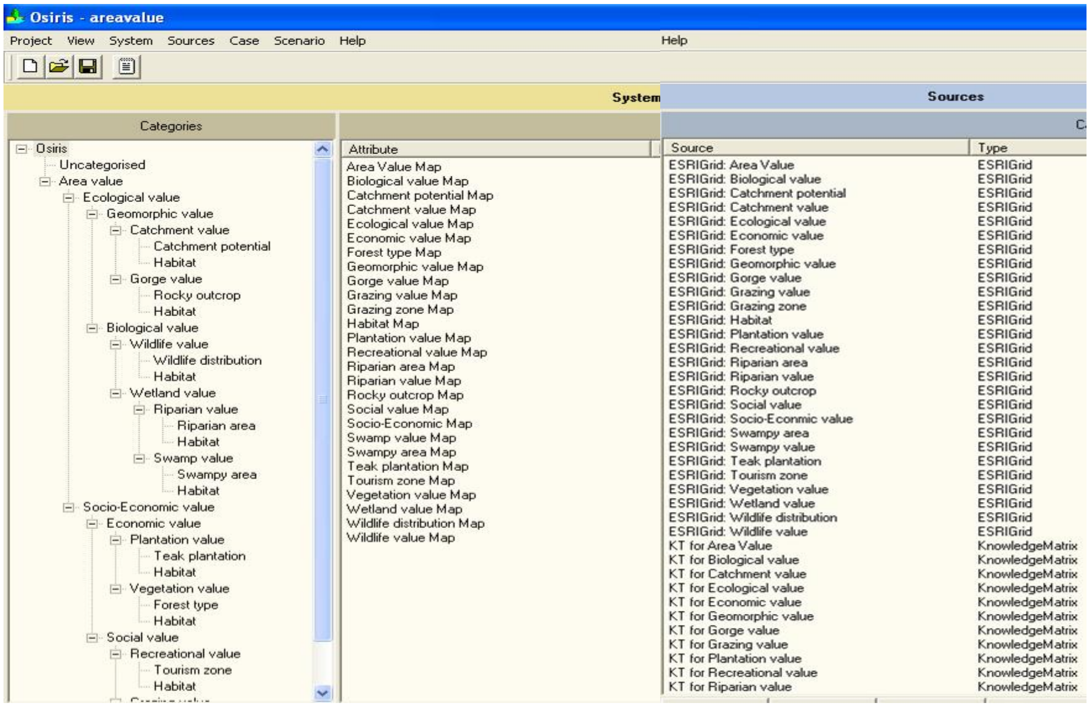


Figure 4. 15: System Attributes and Sources in the Area Value model for the study area

The following base maps are connected to the ESRI legend files in the system attributes:

Maps related to the Ecological Value

Catchment value Map

Gorge value Map

Wildlife value Map

Wetland (Riparian & Swampy) value Map

Map related to flammability

Habitat Map

Maps related to the Socio-Economic Value

Economic (Plantation & Vegetation) value Map

Social (Recreational & Grazing) value Map

A base cross map is used to generate Area Value Map based on Ecological and Socio-Economic considerations

4.8.1.3. Case Dependency in Area Value model

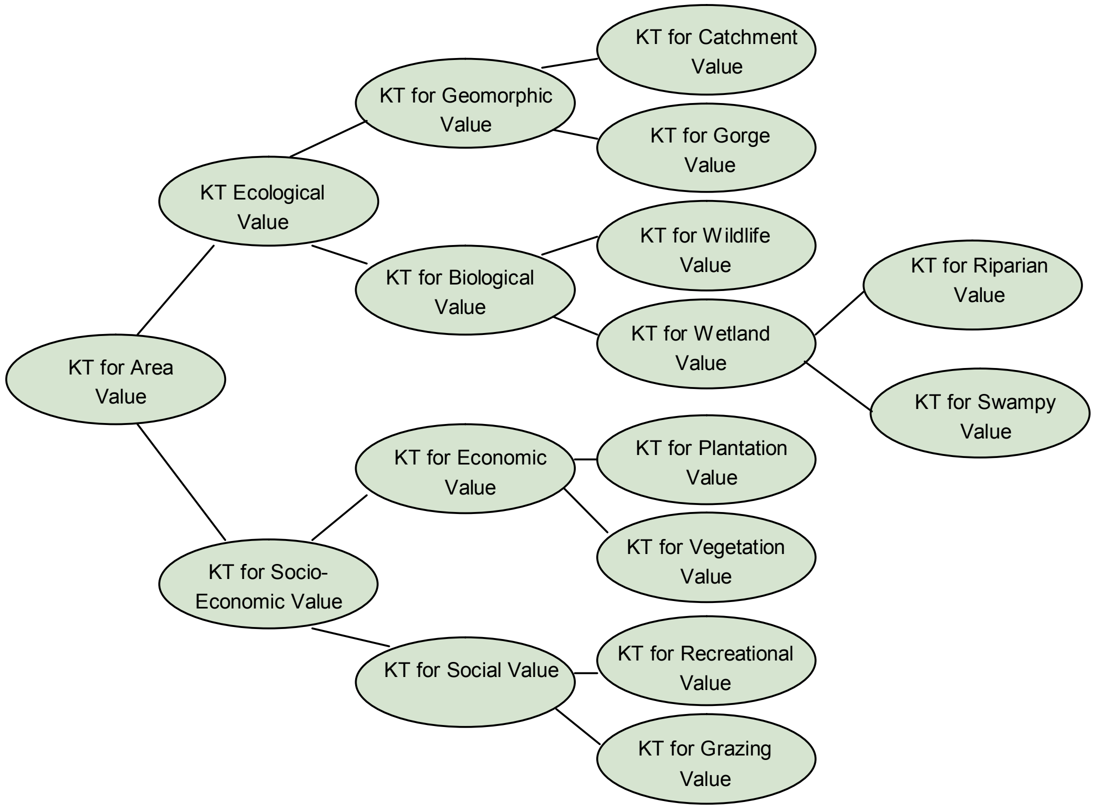


Figure 4. 16: Flow diagram showing case dependency for Area Value model

4.8.1.4. Development of Scenarios in Area Value model

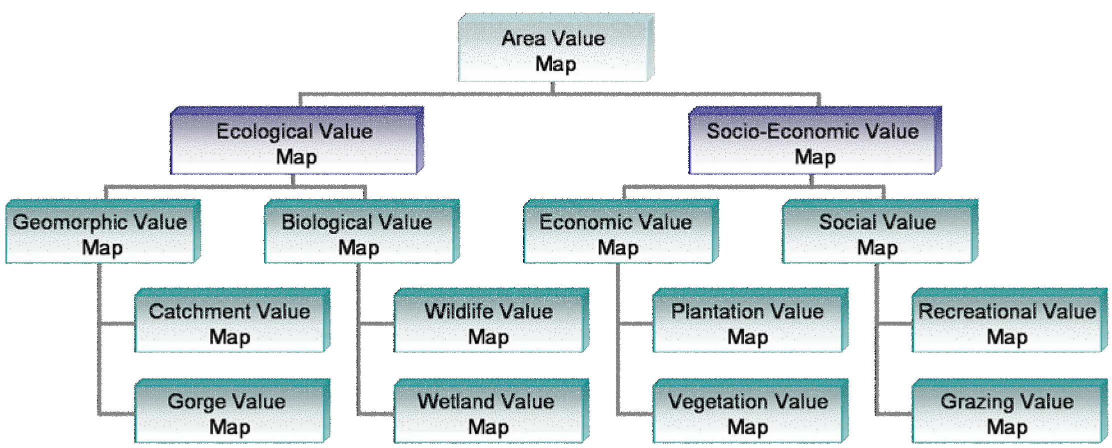


Figure 4. 17: Flow diagram showing Scenario for Area Value model

4.8.2. Standardization of Parameters for Area Value model

All the data are brought into ordinal values as low, moderate, high and extreme.

4.8.3. Data Requirements for Mitigation Strategy model

Mitigation strategy model has been developed considering the forest fire likelihood as per causative factor, value of the area and various management interventions. This model also envisages the GEOPS framework. In respect of mitigation strategy, only manned and unmanned management features have been considered. The natural anti-causative factors, especially, rocky outcrop has not been considered. However, riverine tract has been considered due to the desilting and maintenance of various checkdams.

4.8.3.1. Generation of System Attributes for the Mitigation strategy model

The first step in the development of the Mitigation strategy model is the generation of System categories and attributes in OSIRIS. This is further connected with the source using ESRI Grid and the Knowledge Matrix.

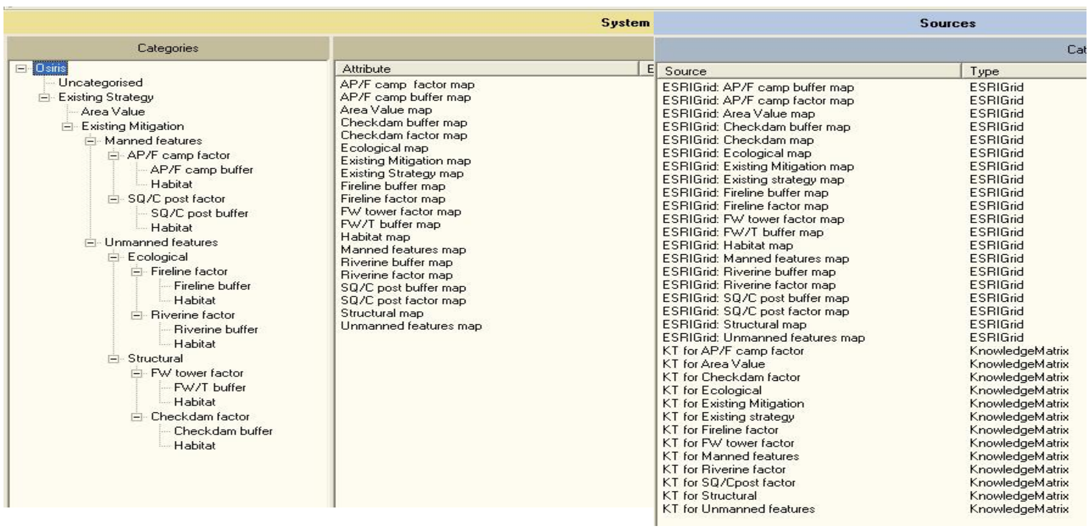


Figure 4. 18: System Attributes and Sources in the Mitigation strategy model for the study area

The following base maps generated are connected to the ESRI legend files in the system attributes:

Maps related to the Management intervention

Antipoaching/Fire camp buffer map

Staff Quarter, Check post buffer map

Fire line buffer map

Riverine buffer map

Check dam buffer map

Fire Watch tower buffer map

Map related to flammability

Habitat Map

Most of the management intervention maps are the same as used in anti-causative factors. Only the natural anti-causative factors have not been considered in the management intervention. Riverine factor, which is also a natural factor, has been considered here as a part of the water harvesting measure carried out in streams.

A base cross map with habitat is used to generate zone of influence of various mitigation measures. The effectiveness of management interventions is analyzed against the Area value map of the area.

4.8.3.2. Case Dependency in Mitigation strategy model

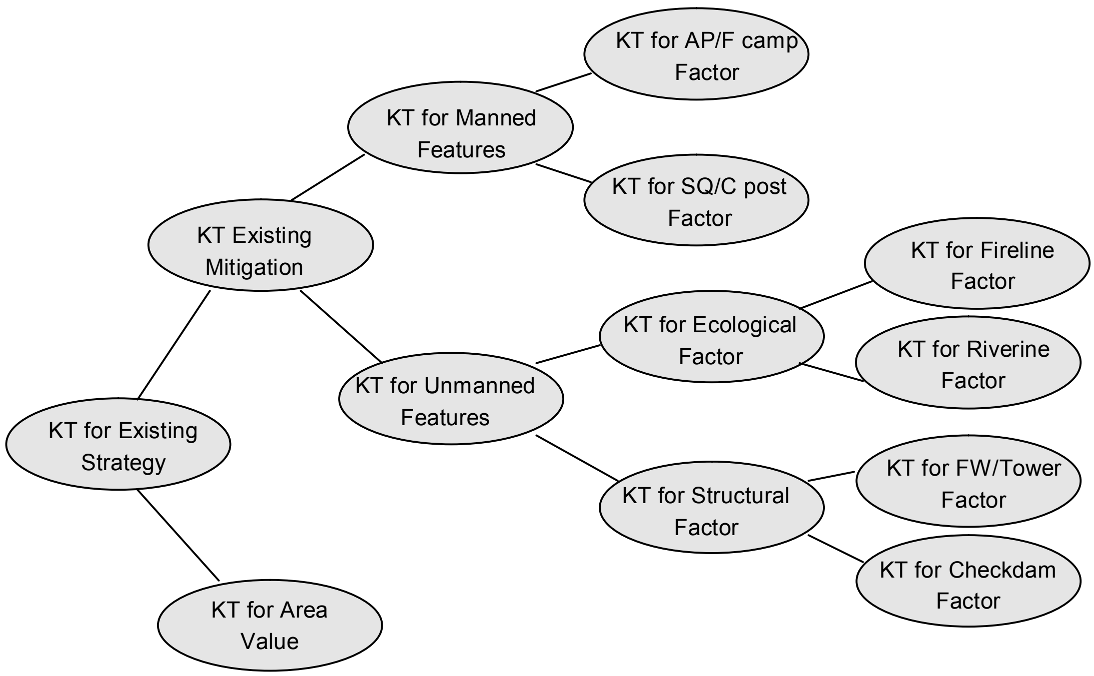


Figure 4. 19: Flow diagram showing case dependency for Mitigation strategy model

4.8.3.3. Development of Scenarios in Mitigation strategy model

The case dependency has been developed as per the above flow diagram to account for different scenarios.

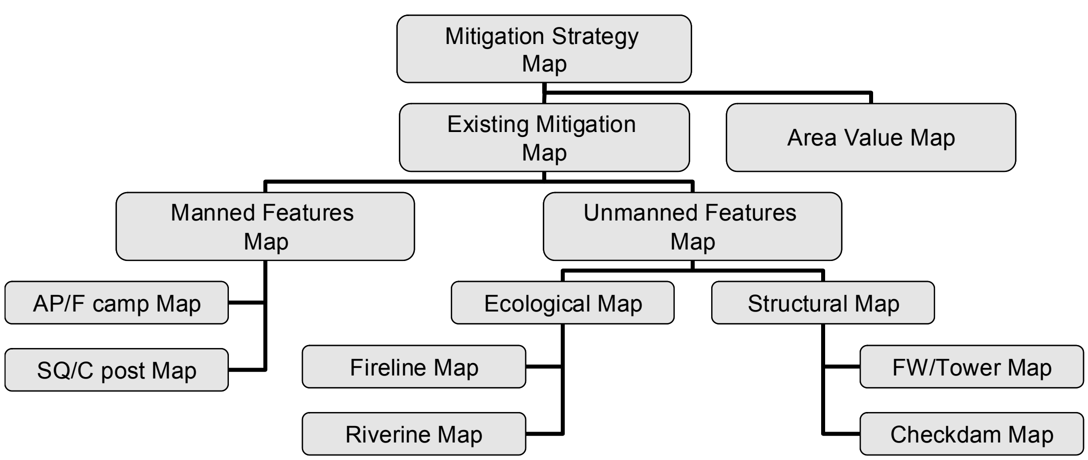


Figure 4. 20: Flow diagram showing Scenario for Mitigation strategy model

4.9. Designing of structure for GIS Customization

Customization is the process of adapting a system to a specific situation. GIS software can be customized in several different ways. Users normally interact with the GIS software system through a typical graphical, menu-driven, icon-based graphical user interface (GUI). Selections from the GUI make calls to the geo-processing tools. The tools in turn lead to the data management functions, responsible for organizing and managing data stored in the database. At the GUI level, it involves configuring the form and appearance of the interface. This includes adding/removing menu choices and buttons, changing the pattern of icons, personalising the color scheme and other characteristics of the windows. At the tools level, customization involves creating macros to automate frequently required processes and adding new functionality. This includes new spatial analysis or data translators. Customization can be carried out at the application or at the object code level. Development environments based on the object-oriented paradigm and those which support interactive graphical development are useful in various applications. Interactive forms can be designed for spatial and non-spatial query using high level language (Visual Basic) and Map Objects.

4.9.1. Data & Software requirements for developing GIS customization

Maps generated as a result of Likelihood, Area value and Mitigation strategy models including base maps of causative and anti-causative factors are taken as inputs in the Map Object library. Attribute tables having spatial and non-spatial data are utilized for running spatial as well as non-spatial query.
It also envisages use of GIS software for advanced analysis. A simple prototype can be developed in the Visual Basic environment using ESRI Map Object 2.1 for the GIS customization. MapObject2 is an Object Linking and Embedding (OLE) control. It can be integrated into other Window-based applications to build a comprehensive information system. For advanced analysis, we can link various GIS software in GUI. The various GIS softwares include – OSIRIS, ERDAS IMAGINE 8.6, ArcView 3.2, ArcMap 9.0 and ILWIS 3.2.

4.9.2. Building GIS for Visualization

When ESRI Map Objects 2.1 components are added to the current project not only the Map control but also automation objects become available for access in Visual Basic. Map Control contains collection of map and image layers based on geographical data set. It displays maps on Visual Basic form. The objects in Map Object 2.1 are grouped into different categories like – Map display object, Data access object, Geometric object, Address matching object and Project object. Data access object establishes connection between the map layer on the Map Control and the data source. The main data access objects include Data Connection, Geo Dataset/s, Record Set, Tables/Description, Fields, Statistics and Strings. There are different types of properties depending on their accessibility to the user. In the GIS customization both Read and Write properties are used.
In Visual Basic, map layer is added to a Map Control through a geo-data source via the Geo Dataset object as its property. A map layer object has a Symbol object as its property to specify how the layer is displayed on a Map control. Certain standard control properties and methods in customization include Extent, Full Extent, Pan, Zoom-in/out, Move, Refresh methods etc.
Both Visual Basic form and controls (including the Map control) use *twips* to measure the coordinates. A *twip* is 1/20 of a printer’s point (1,440 twips = 1 inch or 567 twips = 1 cm). It is screen independent and origin is at the top-left corner of the form or control. The form coordinates are used to measure the locations on the Visual Basic forms and the controls. The three events of the Map control, which return the X, Y position of the mouse in form or screen units (twips) include – MouseDown, MouseMove and MouseUp. The Map control also provides methods to convert between form coordinates and map coordinates based on the current map extent. This includes FromMapDistance/Point to ToMapDistance/Point.

Map control has a special layer known as TrackingLayer. It is not included in the layers collection. The TrackingLayer objects are used to display features dynamically on the Map control. It is suitable for displaying the real time positional data. A single object, called event, that can be added to the TrackingLayer object includes Point, Line, Rectangle, Polygon and Ellipse.

Feature selection is done with the help of Recordset object. The Recordset is the key to interact with the data in the attribute table of a map layer. The Recordset is not a creatable object, but can be accessed via the Records property of a MapLayer. The Recordset object has the Fields property that returns the Fields object of the Recordset object. Individual Field object in the Field collection can be accessed by the name of the Field or index number. The Recordset object also helps in the creation of Statistics object by the CalculateStatistics method. It provides simple statistical information on the values of the numeric field in the Recordset object. The three methods of feature selection of MapLayer object include –

SearchByExpression (Set variable = object.SearchExpression (expression))

SearchByDistance (Set variable = object. SearchByDistance (shape, tolerance, expression))

SearchByShape (Set variable = object. SearchShape (shape, searchMethod, expression))

The result of the query is a RecordSet object that contains only those records that satisfy the question condition.

5. Analysis

This chapter provides an analysis of the various causative and anti-causative factors of forest fire vis-à-vis fire burnt areas and the zone of influence of each factor. It provides an insight into the development of the forest fire likelihood model with identification of various parameters, pair-wise comparison of knowledge matrix, generation of fire risk scenarios including realistic assessment and validation of the model. The chapter also details the parameters required for the computation of area value including prioritization of area value. It also highlights the various management interventions and approach for prioritizing the mitigation strategy with evaluation of existing mitigation measures and suggested redeployment of certain critical ones. Finally, the chapter provides the GIS customization carried for easy perception of the forest fire likelihood model and various factors responsible for the same including related area value and management interventions. It also provides an easy access to the user for detailed analysis and performing various spatial and non-spatial queries.

5.1. Introduction

Statistical data analysis provides an opportunity for describing the forest fire likelihood in a wildlife habitat as accurately as possible. We can describe the forest fire likelihood with the help of causative and anti-causative factors by assigning a level of confidence about these factors. This provides a good understanding of the problems faced and allows more knowledge decisions to be made. It also provides a means to detect and test the existing management interventions.

5.2. Analysis of causative factors of forest fire

As suggested in the methodology, various causative factors were quantified considering their zone of influence into 4 categories viz. extreme, high, moderate and low. In respect of antlers, quantification has been carried out as per the available census data for three years in accordance to the King's Transect method (Annex 5.1). Antler collection is mainly by the local tribal communities who are well versed with the distribution pattern of the deer population and set fire (Johnsingh, 1986). For poaching, last 10 years data of elephant poaching has been considered for identifying the poaching hotspot. It forms the organized crime and setting of fire by the poachers in the area. The target is the resident population during the pinch period inside the PA. Incidences of elephant poaching are quite regular in the area as the data does indicate towards the death of atleast 1-2 males/ year for ivory (Annex 5.2). In respect of tourism and grazing, the study area has the delineated zone and through proximity function buffer has been generated. Similarly, adjoining estates, enclosed settlements and peripheral villages have limited zone of influence and buffers have been generated in respect of these causative factors (Fig.5.1). From Table 5.1 and Fig 5.2, it is quite evident that the antler collection constitutes for the major causative factor in terms of extreme and high categories. This is followed by the tourism, poaching and grazing. The demographic dependent influence of enclosures (enclaves) and ex-closures (peripheral villages and estates) is very much limited.

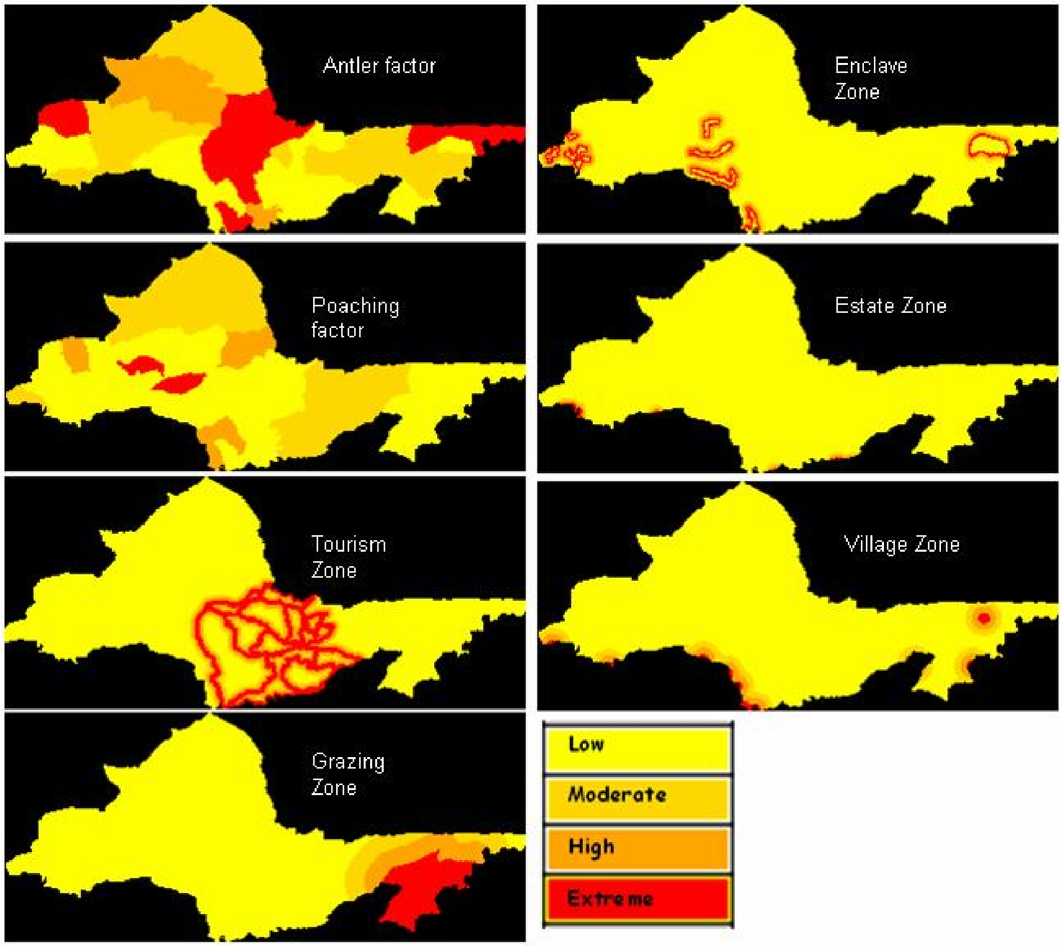


Figure 5. 1: Quantification & Zone of influence of Causative factors

	Causative Factors (Zone of influence in %)						
	Antler	Poaching	Tourism	Grazing	Enclave	Estate	Village
Low	27.42	53.64	75.21	82.22	89.74	98.69	91.23
Moderate	38.30	36.41	5.29	4.70	3.38	0.65	5.18
High	13.08	7.35	8.15	5.43	3.52	0.43	2.88
Extreme	21.20	2.60	11.36	7.65	3.36	0.23	0.71

Table 5. 1: Table showing Zone of influence of causative factors (in %)

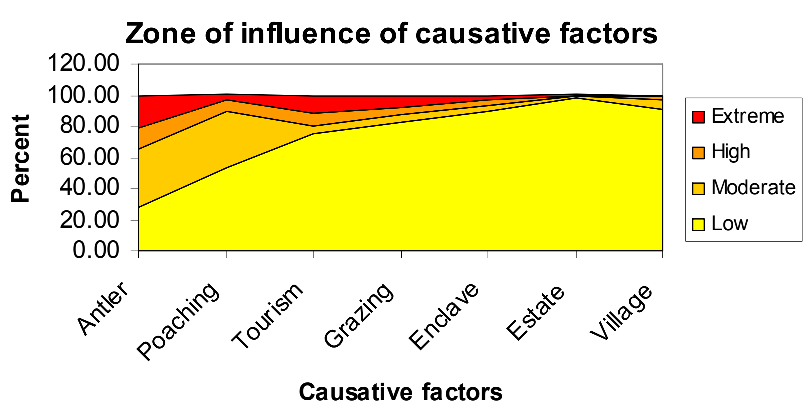


Figure 5. 2: Graph showing Zone of influence of individual causative factors

5.2.1. Overlay of Burnt Areas (1991-1995) with Causative Factor Map

Overlay function forms the key computational activity in this study. It envisages combining of the data layers and new layer output is generated with new information. The principle in overlay function is the combination of features occupying the same location. Layers can be combined using different operators viz. arithmetic, relational and conditional and with many different functions (de By, 2004). It is also seen that the computation is simpler for raster data as compared to the vector layers.

The images were procured for 2 phases to see the influence of causative factors and effectiveness of anti-causative factors. The tourism as a factor was controlled in the year 1995 and anti-poaching/ fire camps as anti-causative factor were established in the year 2000. The burnt areas follow a definite trend in the first phase (1991-95) which continues initially in the second phase also when anti-causative factors become operational. However, certain deviation is observed in the year 2004 and 2005, when fire incidences occurred in the new areas (fig 5.3). This can be explained by the overlay of the causative factor map with the particular year fire map to establish the major causative factor/s responsible for the fire in the area (fig 5.4).

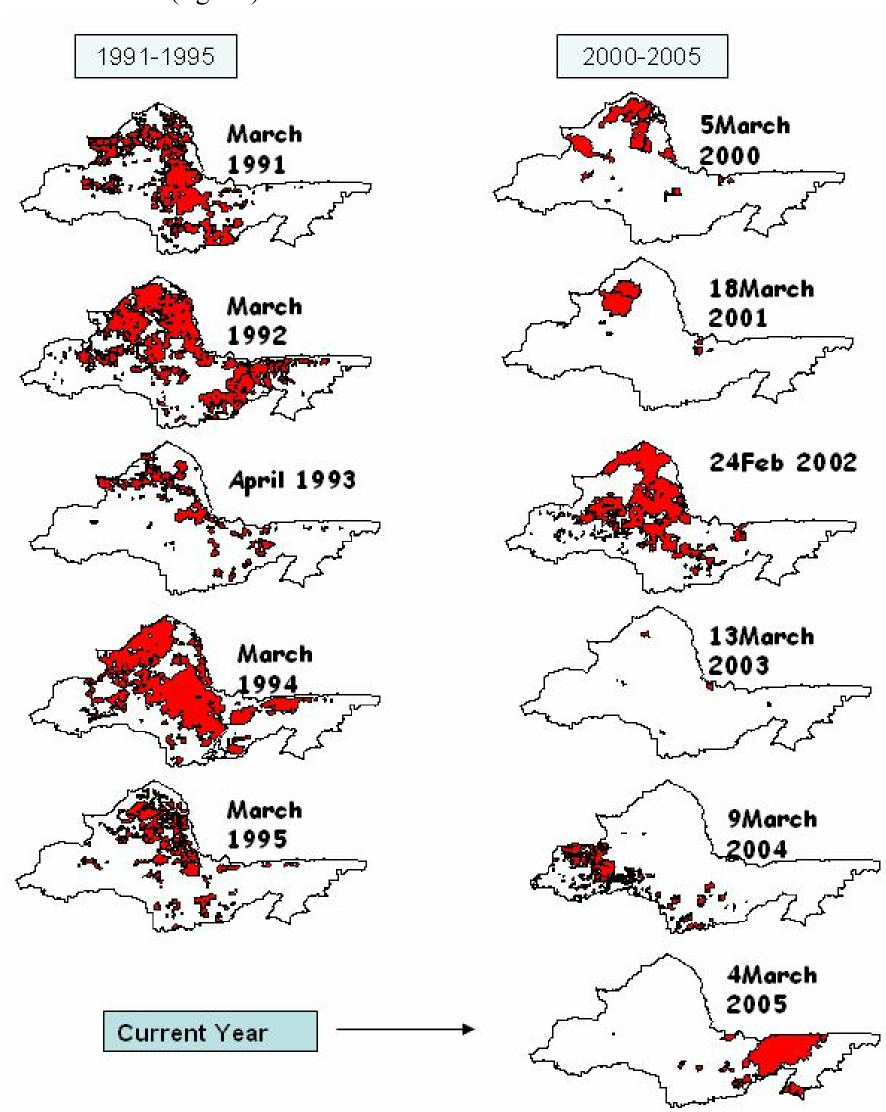


Figure 5. 3: Burnt area for 2 phases (1991-95 and 2000-05)

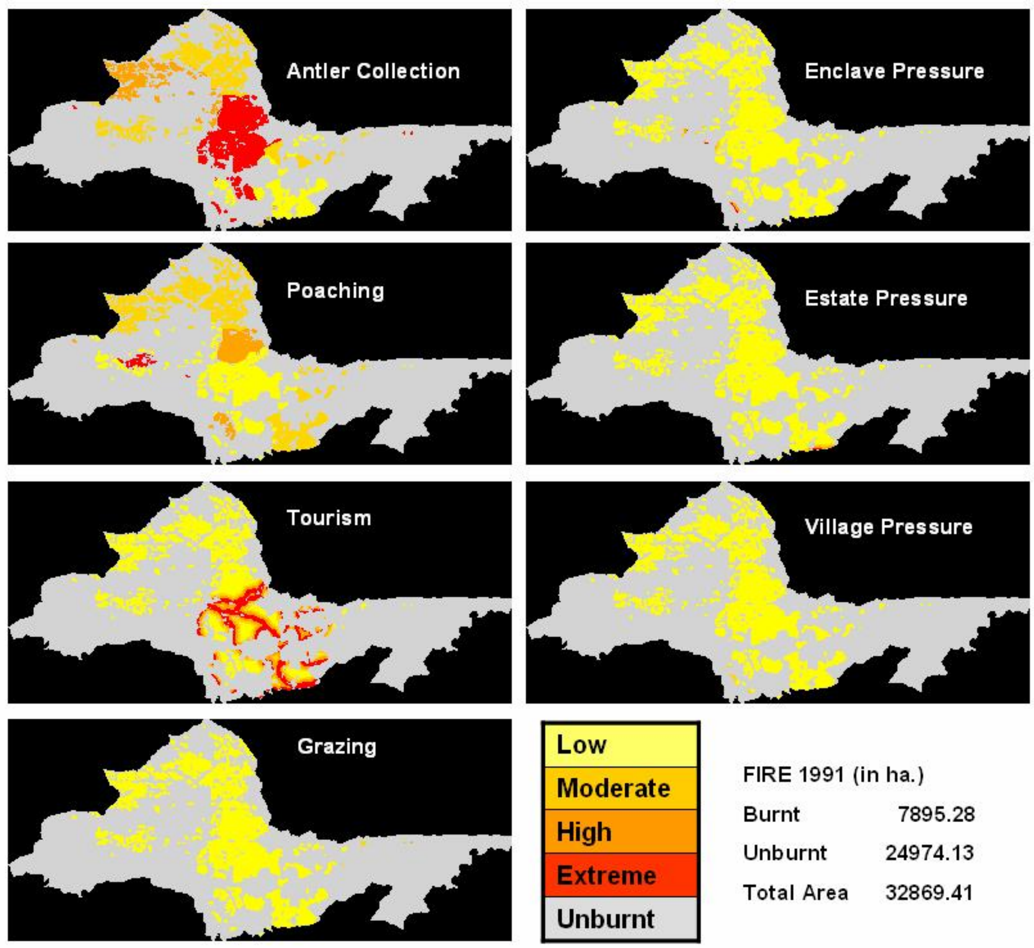


Figure 5. 4: Overlay of burnt area (1991) with the causative factor map

Factor	FIRE 1991 (in ha.)			
	Low/ Nil	Moderate	High	Extreme
Antler	1302.90	2713.32	1197.21	2685.67
Poaching	2857.58	3896.16	968.54	176.82
Tourism	4933.46	689.11	1045.12	1231.41
Grazing	7869.99	22.92	6.19	0.00
Enclaves	7806.87	36.20	36.38	19.65
Estates	7811.24	45.12	34.02	8.73
Villages	7861.81	36.93	0.36	0.00

Table 5. 2: Table showing influence of causative factor vis-à-vis burnt area (1991)

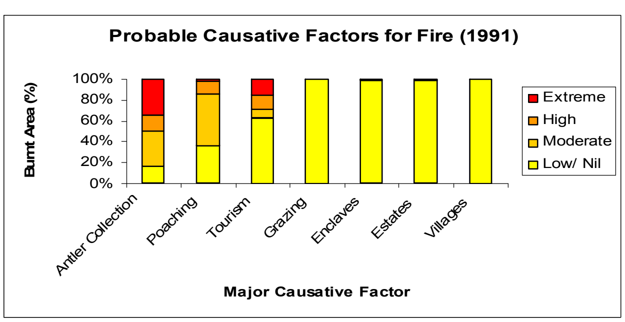


Figure 5. 5: Graph showing the major causative factor vis-à-vis burnt area (1991)

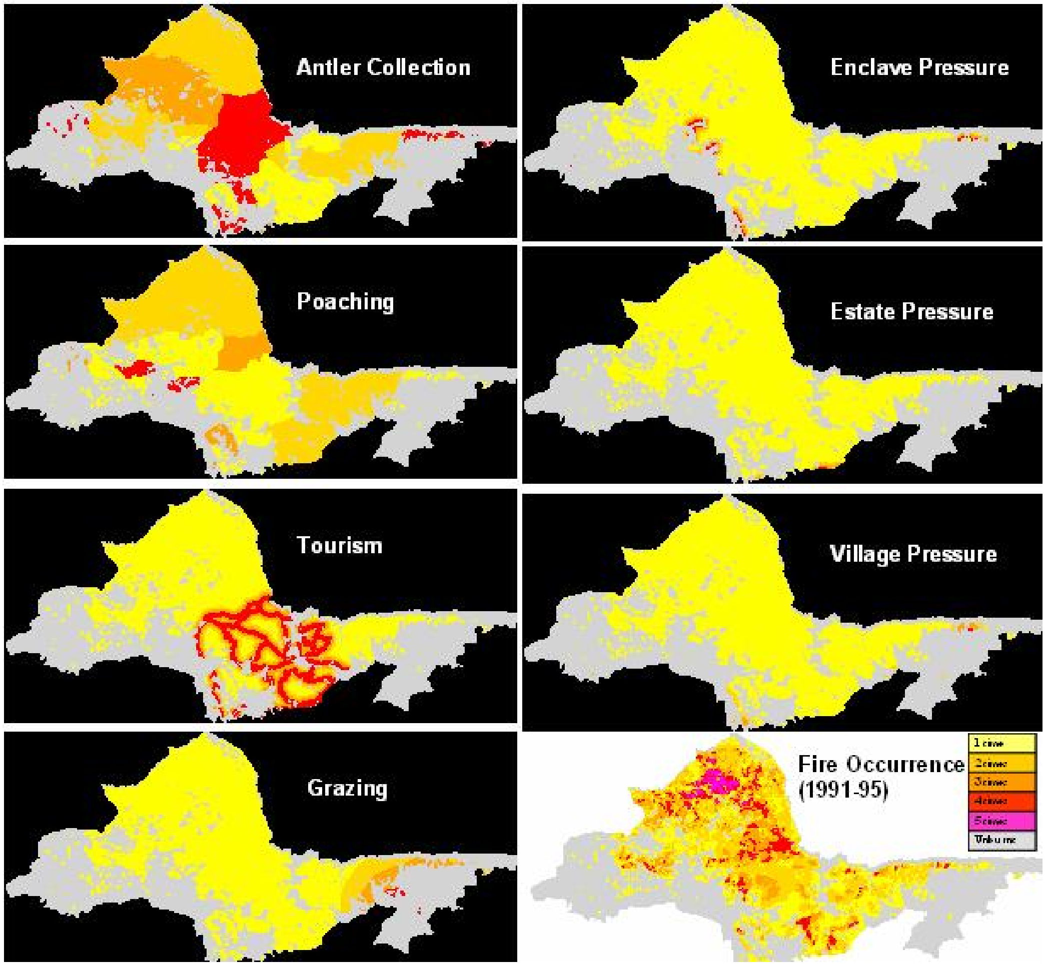


Figure 5. 6: Overlay of cumulative burnt area (1991-95) with the causative factor map

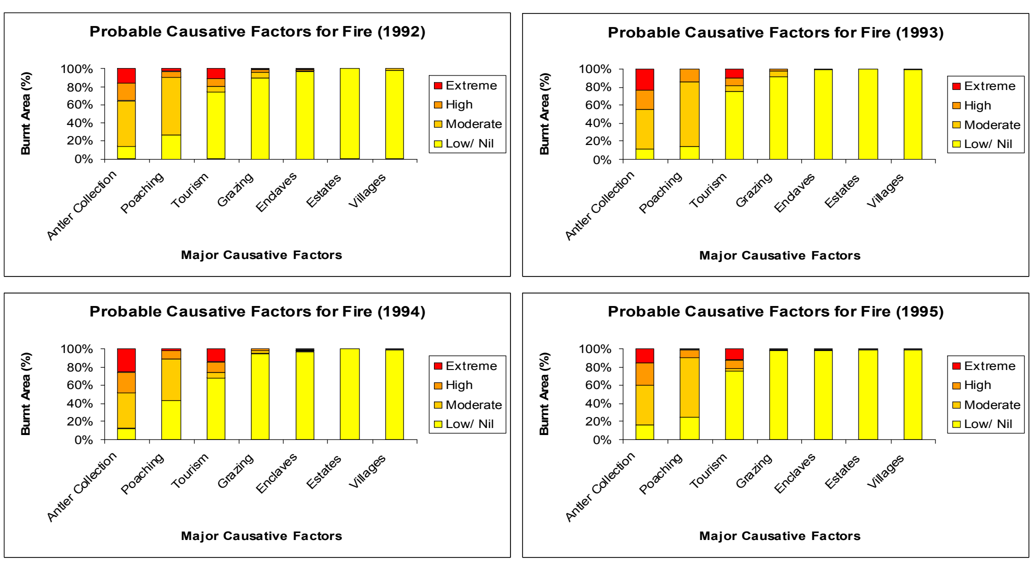


Figure 5. 7: Graphs showing the major causative factor vis-à-vis burnt area (1992-95)

The fire occurrences from1991-95 thus show the same trend in almost all the years when it comes to the major causative factors. The cumulative results are shown below:

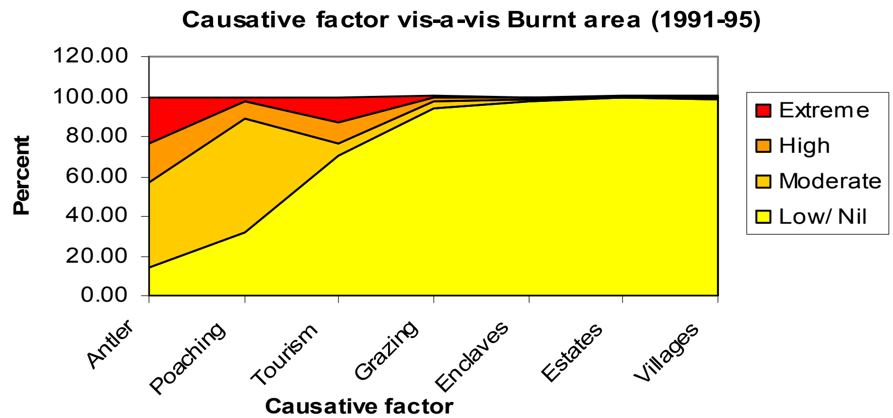


Figure 5. 8: Graph showing Causative factor vis-à-vis cumulative burnt area (1991-95)

Factor	% Fire burnt 1991-95			
	Low/ Nil	Moderate	High	Extreme
Antler	14.03	42.50	20.01	23.46
Poaching	32.27	56.46	9.26	2.01
Tourism	70.38	6.35	10.26	13.01
Grazing	94.27	3.56	2.01	0.17
Enclaves	97.81	0.95	0.76	0.47
Estates	99.50	0.29	0.17	0.04
Villages	98.94	0.74	0.30	0.03

Table 5. 3: Table showing influence of causative factor vis-à-vis cumulative burnt area (1991-95)

From the results of fire burnt areas from 1991-95, it is quite evident that antler collection contributes to the major causative factor for forest fire occurrence. This is followed by uncontrolled tourism and poaching. There could be possible overlaps between antler collection and poaching as the same is dependent on the distribution pattern of wildlife vis-à-vis its habitat. Regarding the overlap of tourism zone, the same has been taken care of by the controlled tourism coming in vogue after 1995. The other factors viz. grazing, pressures from enclave, estate and village have separate zone of influence.

5.3. Analysis of anti-causative factors of forest fire

The zone of influence of the anti-causative factors has been computed by *buffer zone generation* using *proximity function*. Different geometric distances have been used for buffer zone for various anti-causative factors. In vector based features, the buffer themselves become polygon features as a separate data layer which eventually can be used for spatial data analysis (de By, 2004).

The undulating terrain of the study area has a good drainage network which supports innumerable perennial and seasonal streams. The riverine patches, semi-evergreen forests and rocky outcrops form the natural anti-causative factors. The distance has been considered primarily as per the patrolling distance in respect of the manned features viz. anti-poaching/ fire camps, staff quarter/ check post. Similarly, unmanned features like fire lines, check dams and fire watch towers have their limited zone of influence. The zone of influence of anti-causative factors is depicted in fig 5.9. Table 5.4 and graph in fig 5.10 depicts the low to extreme category of fire likelihood as per zone of influence.

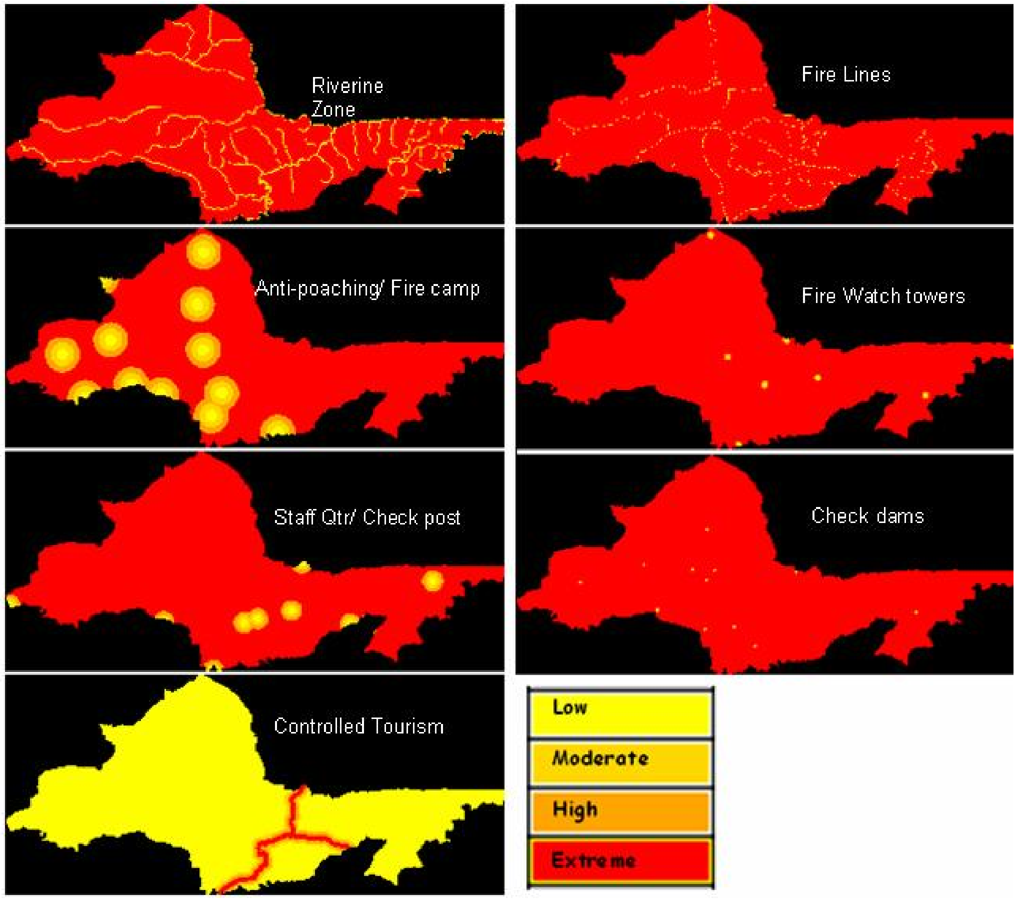


Figure 5. 9: Quantification & zone of influence of anti-causative factors

	Zone of influence (Likelihood in %)						
	AP/F camp	SQ/C post	Riverine	Rocky	Fire line	F/W tower	Check dam
Low	2.36	0.51	3.19	2.67	1.90	0.07	0.03
Moderate	6.74	1.62	2.34	0.05	0.14	0.21	0.08
High	10.64	2.50	2.32	0.03	0.11	0.33	0.14
Extreme	80.26	95.37	92.15	97.25	97.85	99.38	99.75

Table 5. 4: Table showing zone of influence of anti- causative factors (in %)

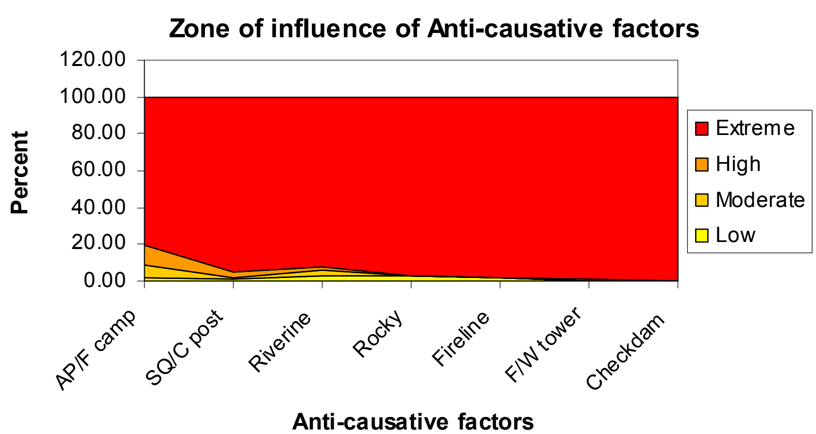


Figure 5. 10: Graph showing zone of influence of individual anti-causative factors

From above, it is evident that anti-poaching/ fire camp (AP/F camp) is the most effective factor in terms of zone of influence. Similarly, riverine (natural feature) also shows a peak in the graph 5.10.

5.3.1. Overlay of Burnt Areas (2000-2005) with Causative Factor Map

The overlay of fire burnt areas with various causative factors is carried out to obtain the pre-dominance of the causative factor in the particular area. The burnt area for 2000-2005 has been considered for the overlay to assess the implications/ effectiveness of anti-causative factors. The only difference in the anti-causative factors in the second phase data (2000-05) when compared with the first phase (1991-95) is the ban on the operation of private vehicles in the tourism zone and stationing of anti-poaching / fire camps in the study area. Results have been obtained as under:

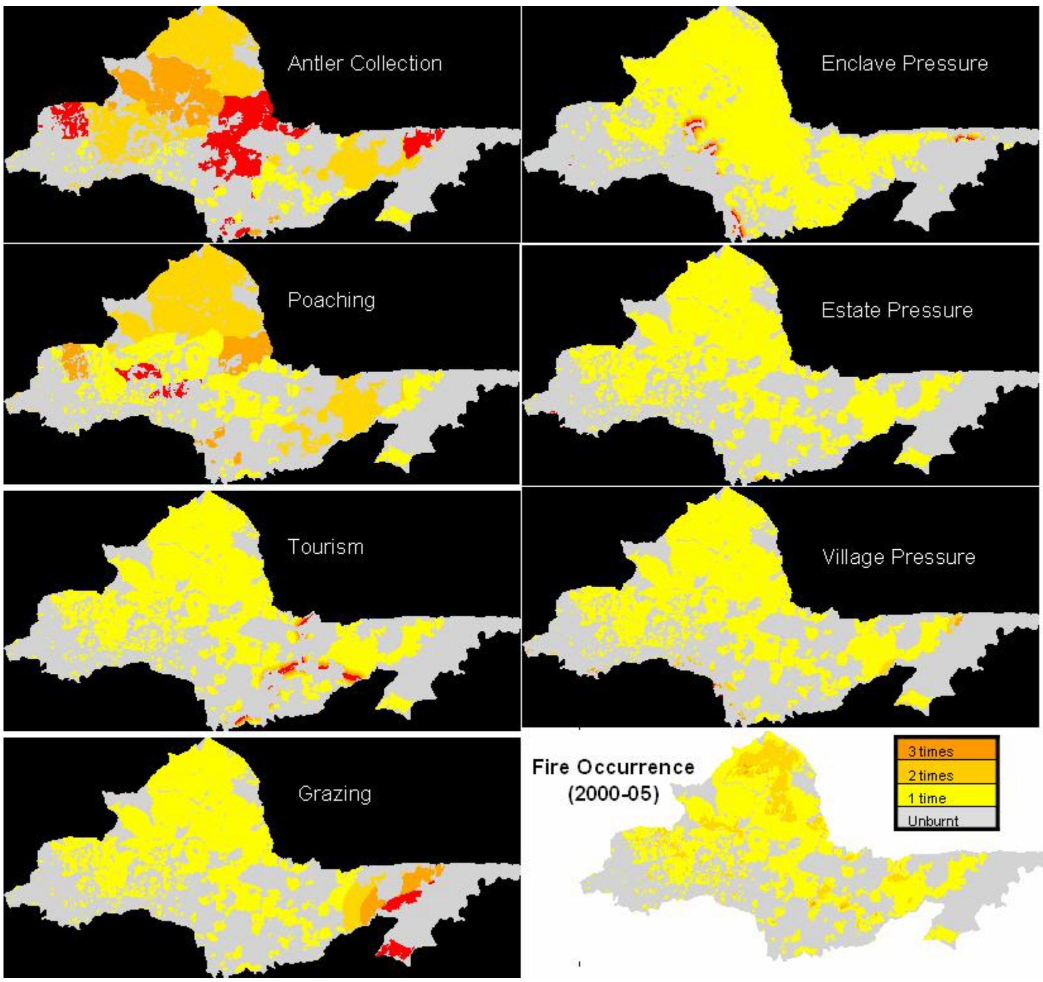


Figure 5. 11: Overlay of cumulative burnt area (2000-05) with the causative factor map

	% Fire burnt (2000-05)			
	Low/ Nil	Moderate	High	Extrem e
Antler	12.83	51.02	17.20	18.95
Poaching	38.46	50.57	8.77	2.20
Tourism	95.55	1.83	1.48	1.15
Grazing	89.60	3.74	4.03	2.64
Enclaves	96.63	1.24	1.22	0.91
Estates	99.79	0.12	0.06	0.03
Villages	97.85	1.65	0.44	0.05

Table 5. 5: Table showing influence of causative factor vis-à-vis cumulative burnt area (2000-05)

The fire burnt areas indicate lesser occurrence in the second phase (2000-05) as is evident from the consolidated map (fig 5.11) and the graph (fig 5.12). Though, the overall trend in terms of major causative factor/s remains the same but anti-causative factors do account for reduction in some. During this phase (2000-2005), there is drastic reduction in the fire occurrence which could be attributed to the anti-causative factors especially stationing of the anti-poaching cum fire camps in the year 2000 and ban on the operation of private vehicles as a result of controlled tourism. There is overall reduction in fire due to antler collection as well as poaching. However, fire due to grazing becomes critical in one year (fig 5.13).

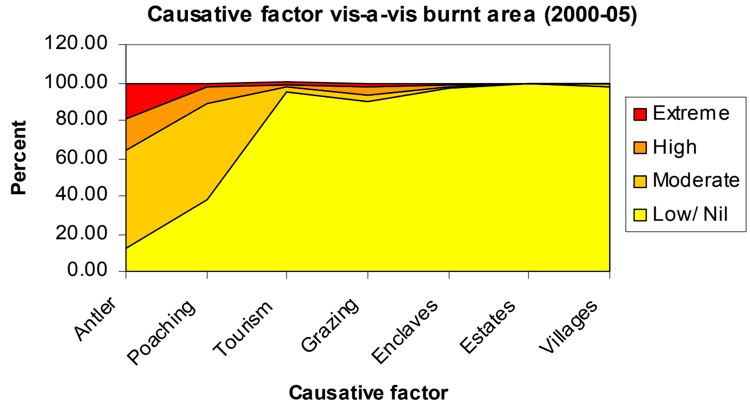


Figure 5. 12: Graph showing Causative factor vis-à-vis cumulative burnt area (1991-95)

5.3.2. Comparison of Burnt Areas in 2 phases

Comparison of Burnt Area in two phases (in ha)		
	1991-95 (Avg)	2000-05 (Avg)
Antler	1295.92	436.2
Poaching	1020.84	307.92
Tourism	446.45	22.29
Grazing	86.38	52.05
Enclaves	33.06	16.86
Estates	7.55	1.07
Villages	15.99	10.75

Table 5. 6: Table showing comparison of average burnt areas (in ha) in 2 phases

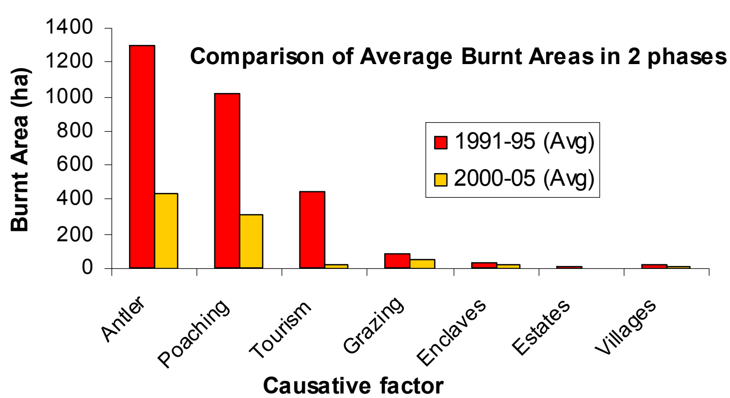


Figure 5. 13: Graph showing influence of causative factor vis-à-vis cumulative burnt area in two phases

The above results establish the operation of a particular causative factor vis-à-vis forest fire in the study area. However, the likelihood of that factor with the forest fire is also dependent on the flammability of the habitat. The development of forest fire likelihood model envisages the need for igniting the area (causative factor), operation of anti-causative factors and flammability of the habitat.

5.4. Implementation of Likelihood model

In implementation of the forest fire likelihood model, it is essential to develop the habitat map (flammability) besides integrating both causative as well as anti-causative factors. The map so generated incorporates the broad classes from the classified vegetation map (fig 5.14). The accuracy assessment of the classified vegetation map has been carried out before generating broad habitat (flammability) map.

5.4.1. Accuracy assessment of classified vegetation map

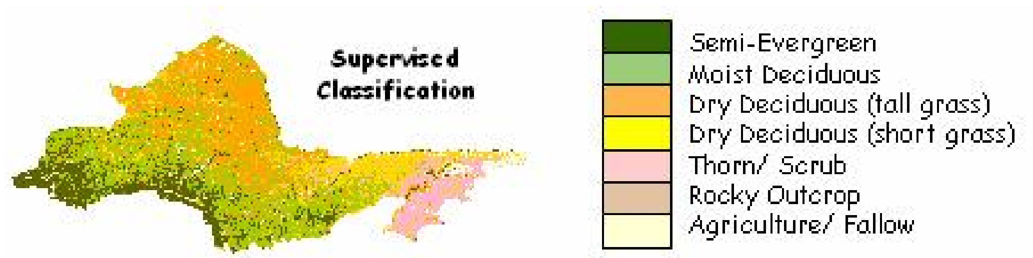


Figure 5. 14: Supervised classification for broad vegetation types

The classification accuracy assessment is not only necessary for having the locational accuracy (Jensen, 1996) but also for having the accurate habitat (flammability) map. This forms the critical input layer with the causative and anti-causative factors map. Ground truth data and map obtained from the forest department have been used for developing the reference set. Verification of the same has been carried out during the field visit. E*rror matrix* has been computed to obtain the *Producer* (omission error) and *User's accuracy* (commission error) (Table 5.7).

ERROR MATRIX												
	SE	MD	DD(T)	DD(S)	S/T	RO	A/F			**Prod Acc**	**User Acc**	**Kappa**
SE	**6**	2	0	0	0	0	0	**8**		85.71%	75.00%	0.7257
MD	1	**21**	3	1	0	0	0	**26**		80.77%	80.77%	0.7134
DD(T)	0	1	**19**	3	0	0	0	**23**		86.36%	82.61%	0.7590
DD(S)	0	1	0	**9**	0	0	0	**10**		60.00%	90.00%	0.8766
S/T	0	0	0	2	**6**	0	0	**8**		100.00%	75.00%	0.7295
RO	0	1	0	0	0	**2**	0	**3**		100.00%	66.67%	0.6580
A/F	0	0	0	0	0	0	**1**	**1**		100.00%	100.00%	1.0000
	7	**26**	**22**	**15**	**6**	**2**	**1**					
										Overall Accuracy = 81.01%		
										Overall Kappa Stats = 0.7530		

Table 5. 7: Table showing Error Matrix computation

Producer's accuracy for the critical vegetation class viz. semi-evergreen, moist deciduous and dry deciduous-tall grass (excepting scrub/ thorn & dry deciduous-short grass) is between 80 to 85% which is reflected in the *User's accuracy* between 75 to 82 %. The scrub/ thorn and dry deciduous-short grass vegetation type ranges between 75 to 100%. The *Overall accuracy* of the classification has been obtained as 81.01% which is considered as good for delineating the broad habitat classes. Similarly, *Kappa stat* of 0.7530 is an indication that the observed classification is 75% better than the one resulting from chance. The Kappa value is somewhat lower than the overall accuracy (0.81) but differences in these two measures is obvious as both incorporate different forms of information from the error matrix. In both situations, accuracy is enough for computation of the broad habitat (flammability) classes.

5.4.2. Generation of broad habitat (flammability) class

The forest type of the study area is primarily deciduous which is quite susceptible to the forest fire. The vegetation types have been grouped depending upon the flammability of the forest type as under:

Extreme - Dry deciduous (tall grass)
High - Moist deciduous, Dry deciduous (short grass)
Moderate - Scrub/ Thorn, Rocky (shrub cover)
Low - Semi-evergreen, Agriculture/ Fallow

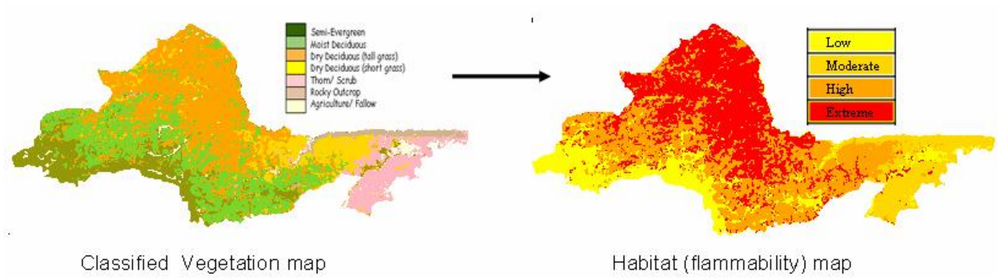


Figure 5. 15: Broad habitat (flammability) types

5.4.3. Identification of variables

The input variables in the Likelihood model have been generated by the cross of habitat (flammability) map with the causative and anti-causative factors (figs 5.16 and 5.17).

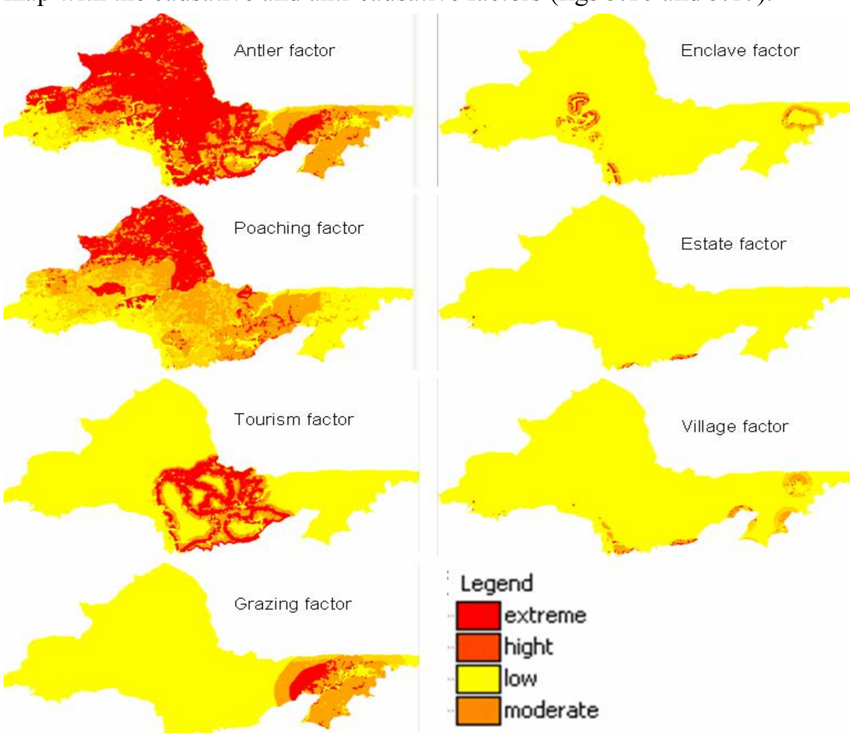


Figure 5. 16: Variables related to causative factors

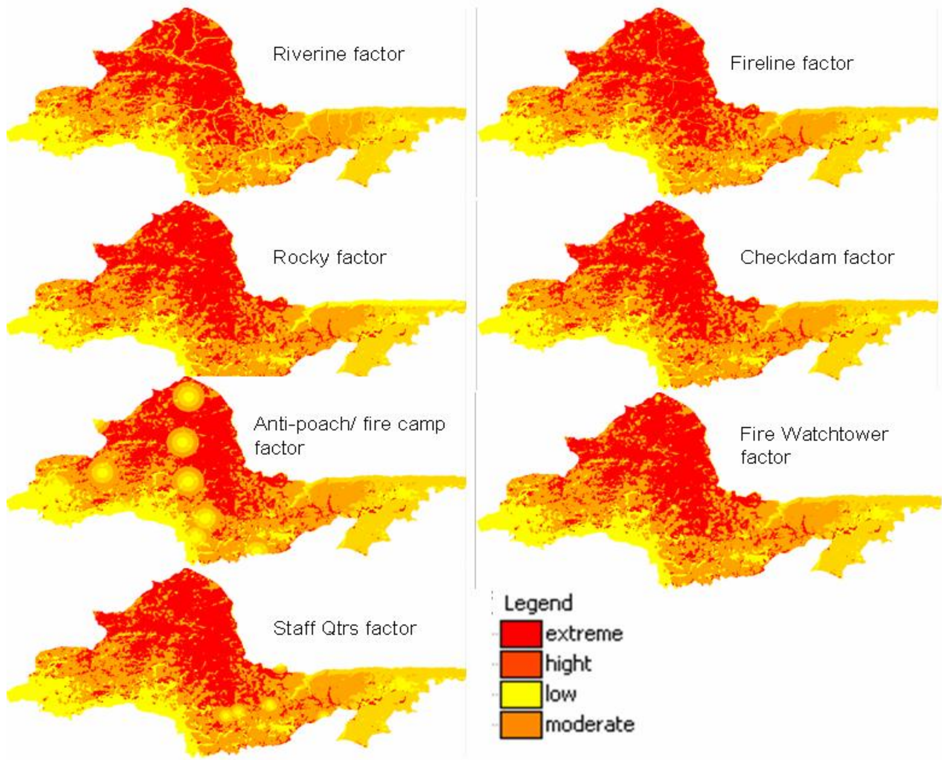


Figure 5. 17: Variables related to anti-causative factors

If we compare the zone of influence of causative factors without habitat flammability (fig 5.1) and with habitat (fig 5.16), we find that the likelihood is comparable in terms of trend and influence. But when we consider the anti-causative factors (figs 5.9 & 5.17), the results and trend are not comparable. This is mainly due to the location of management interventions which needs redeployment in respect of manned structures.

CAUSATIVE FACTORS				
	Zone of influence in terms of fire (%)			
	Low	Moderate	High	Extreme
Antler	18.72	2.89	24.40	53.99
Poaching	28.72	17.85	30.62	22.81
Tourism	78.35	0.00	8.78	12.87
Grazing	84.03	1.78	10.91	3.28
Enclave	95.63	0.57	2.64	1.16
Estate	99.47	0.00	0.36	0.17
Village	95.66	1.89	2.10	0.35
ANTI-CAUSATIVE FACTORS				
Riverine	19.37	12.25	36.03	32.35
Rocky	19.74	9.01	36.35	34.91
AP/F camp	18.90	16.24	36.98	27.88
SQ/C post	17.63	12.36	35.98	34.04
Fireline	18.99	11.30	35.49	34.23
Checkdam	17.33	11.45	36.40	34.82
FW/tower	17.38	11.53	36.41	34.68

Table 5. 8: Table showing Zone of influence of various factors considering habitat

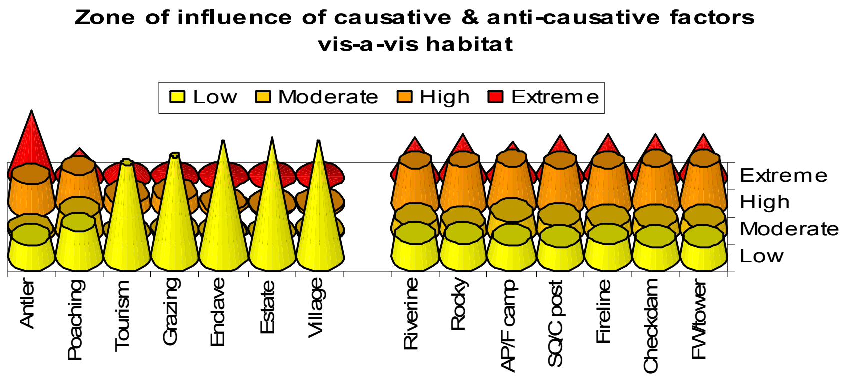


Figure 5. 18: Graph showing the zone of influence of causative and anti-causative factors with habitat

From the graph, we can see that antler factor contributes significantly in the likelihood of fire followed by poaching. Whereas in anti-causative factors, natural factors play an important role and AP/F camp (manned structure), which is quite significant as per its zone of influence, needs redeployment in certain places.

5.4.4. Pair-wise comparison

OSIRIS supports pair-wise comparison of the maps which operates on the premise of combination of two maps. The *cross operation* in the software performs an overlay of two grid maps by comparing pixels at the same positions in both the maps. The pair-wise comparison is performed on an ordinal scale of the standardized data input. In respect of forest fire likelihood model, both causative and anti-causative factors generate the following streams by pair-wise comparison:

Causative Factor Maps

[Animal distribution dependent = Antler factor + Poaching factor]

[Management dependent = Tourism factor + Grazing factor]

[Demographic dependent = Enclave factor + Estate factor + Village factor]

[Biotic pressure dependent = Management dependent + Demographic dependent]

[Likelihood (Causative) = Animal distribution dependent + Biotic pressure dependent]

Anti-causative Factor Maps

[Natural features = Rocky feature + Riverine feature]

[Manned features = Anti-poaching/ fire camp + Staff Quarter/ Check post]

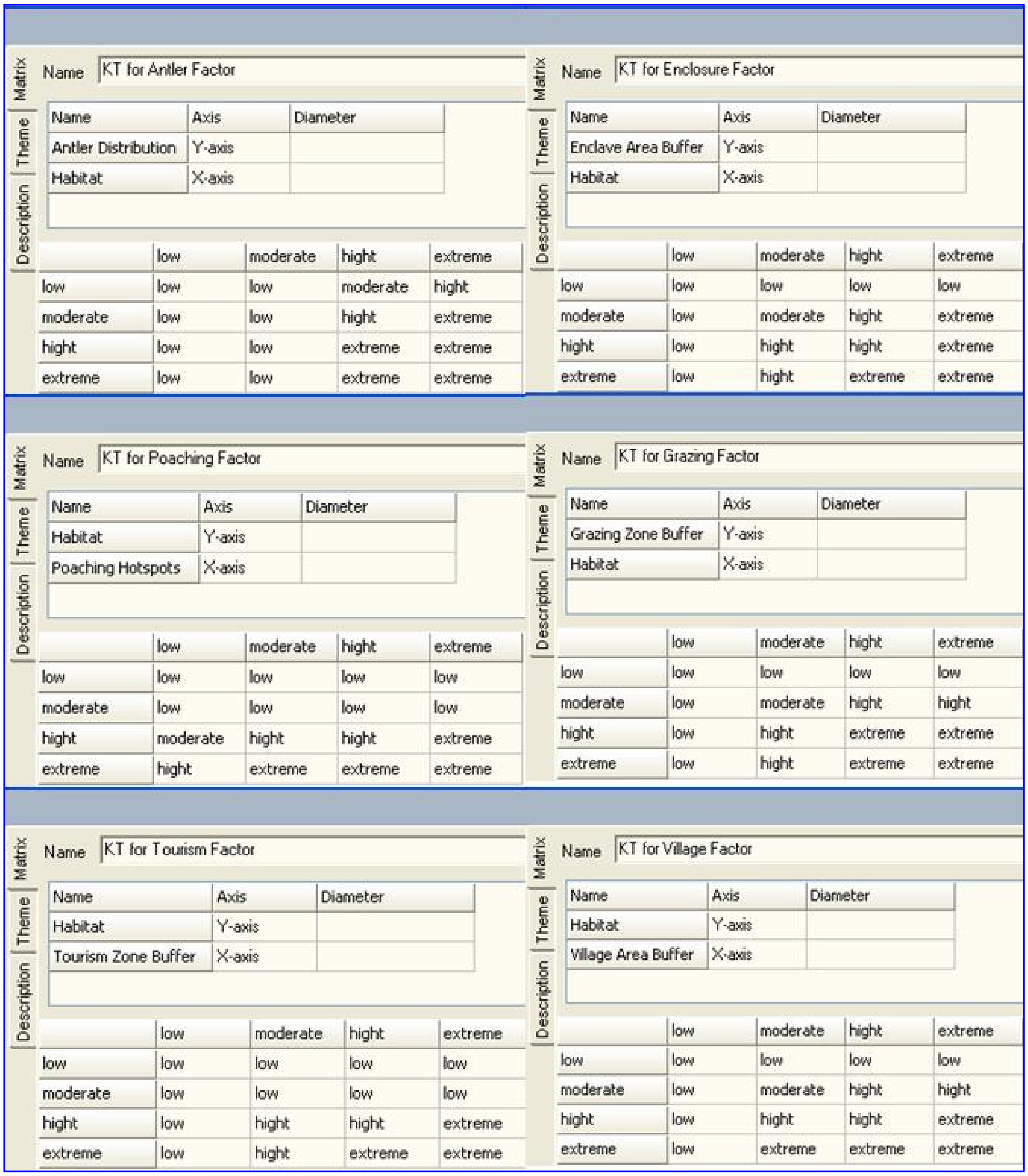
[Unmanned features = Fire line + Fire watch tower + Check dam]

[Management feature = Manned features + Unmanned features]

[Anti-causative factor = Natural features + Management features]

5.4.5. Generation of knowledge matrix

A knowledge matrix connects to one or more system attributes and is visualized in the form of a table (fig 5.19). A knowledge matrix is defined on the basis of themes. Every dimension is in conformity with a theme. Each dimension is defined in combination with a different theme. The outcome is also based on a theme and can correspond with a theme in one of the dimensions. A theme consists of classes (low, moderate, high and extreme) and has a value in the form of a colour.



Name: KT for Antler Factor

Name	Axis	Diameter
Antler Distribution	Y-axis	
Habitat	X-axis	

	low	moderate	hight	extreme
low	low	low	moderate	hight
moderate	low	low	hight	extreme
hight	low	low	extreme	extreme
extreme	low	low	extreme	extreme

Name: KT for Enclosure Factor

Name	Axis	Diameter
Enclave Area Buffer	Y-axis	
Habitat	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	moderate	hight	extreme
hight	low	hight	hight	extreme
extreme	low	hight	extreme	extreme

Name: KT for Poaching Factor

Name	Axis	Diameter
Habitat	Y-axis	
Poaching Hotspots	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	low	low	low
hight	moderate	hight	hight	extreme
extreme	hight	extreme	extreme	extreme

Name: KT for Grazing Factor

Name	Axis	Diameter
Grazing Zone Buffer	Y-axis	
Habitat	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	moderate	hight	hight
hight	low	hight	extreme	extreme
extreme	low	hight	extreme	extreme

Name: KT for Tourism Factor

Name	Axis	Diameter
Habitat	Y-axis	
Tourism Zone Buffer	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	low	low	low
hight	low	hight	hight	extreme
extreme	low	hight	extreme	extreme

Name: KT for Village Factor

Name	Axis	Diameter
Habitat	Y-axis	
Village Area Buffer	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	moderate	hight	hight
hight	low	hight	hight	extreme
extreme	low	extreme	extreme	extreme

Figure 5. 19: Knowledge matrix for causative factors

Different scenarios have been generated by changing the ordinal values in the knowledge matrix. The values have been considered keeping the critical causative factor vis-à-vis flammability of the habitat. The results are evident in the fire risk scenarios. Similarly, matrices have been prepared for various pair-wise comparisons of the resultant themes.

5.4.6. Generation of fire likelihood scenarios

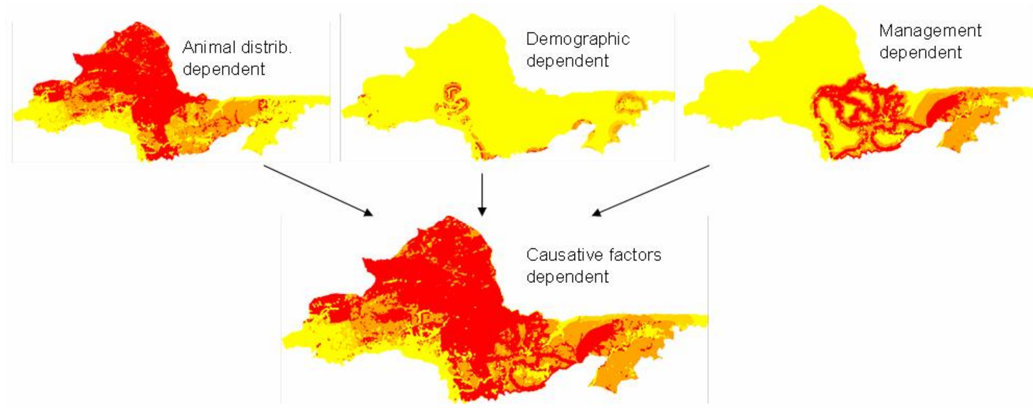


Figure 5. 20: Generation of Fire Likelihood scenario for Causative factors

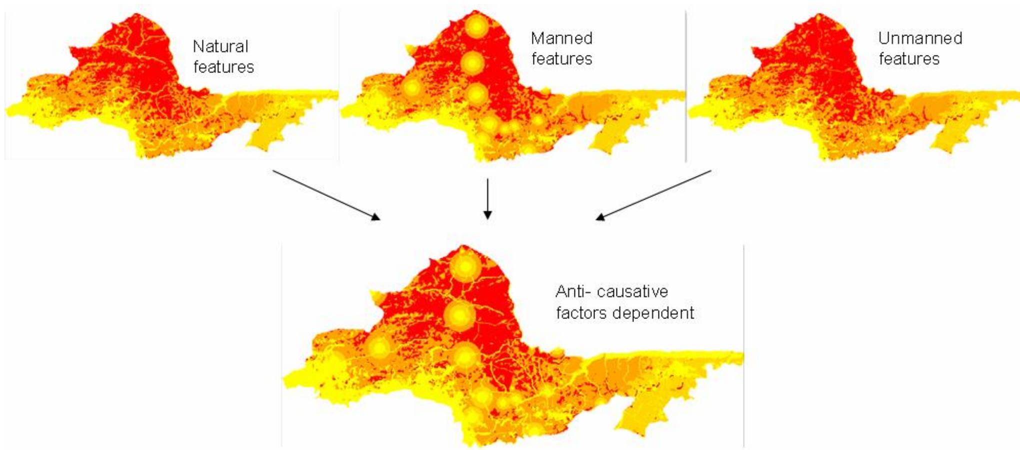
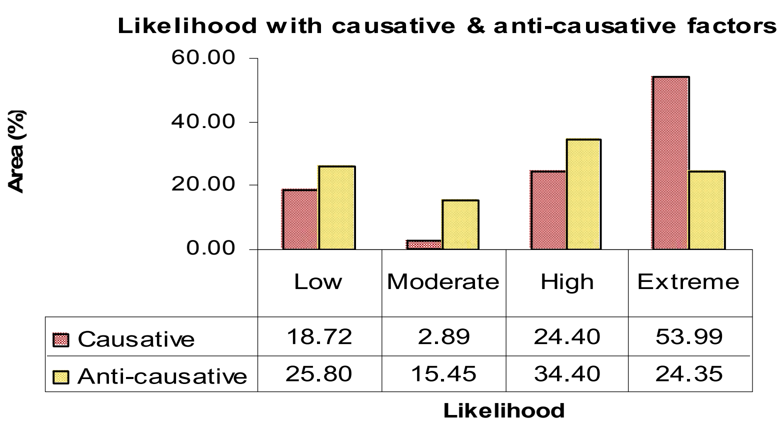


Figure 5. 21: Generation of Fire Likelihood scenario for Anti-causative factors



	Low	Moderate	High	Extreme
Causative	18.72	2.89	24.40	53.99
Anti-causative	25.80	15.45	34.40	24.35

Figure 5. 22: Graph showing influence of causative and anti-causative factors

From the graph, it is quite evident that there is reduction in the extreme category of likelihood due to the anti-causative factors. There is related increase in the other categories as a result of above reduction. The likelihood model (without anti-causative factors) accounts for nearly 54% in the extreme category, 25% in the infrequent high category & 21% in the low or 'nil' category.

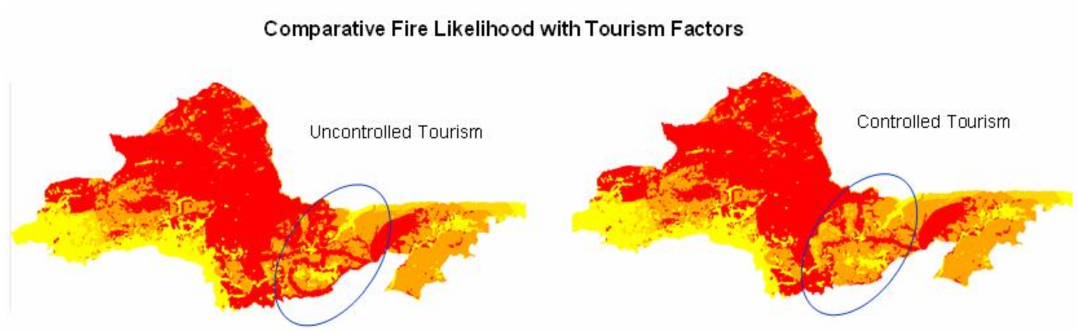


Figure 5. 23: Influence of tourism as a factor on Likelihood model

We can generate various scenarios from the model to explain for the influence of various causative as well as anti-causative factors. For instance, in uncontrolled tourism (before1995) and controlled tourism (after 1995), we observe change in the scenario of the likelihood of forest fire (fig 5.23). With the controlled tourism we can see that there is reduction in the extreme category fig 5.24).

Similarly, anti-causative factors, especially anti-poaching camps became operational since 2000 and the same is also reflected in the overall reduction of the forest fire.

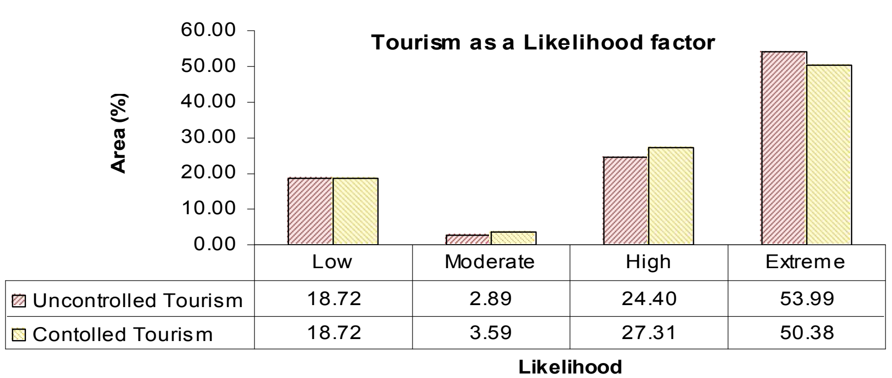


Figure 5. 24: Graph showing influence of tourism as a factor on Likelihood model

5.4.7. Realistic assessment of the likelihood of forest fire from the model

The forest fire in the study area is caused by the various causative factors and the time series data can help in the realistic assessment of the likelihood ness of the fire (table 5.9).

1991-95		2000-05		~1991-05	
Times	Percent	Times	Percent	Times	Percent
1	19.75	1	39.26	1	10.91
2	19.76	2	7.58	2	10.08
3	10.33	3	0.17	3	16.77
4	4.62		**47.01**	4	14.05
5	1.2			5	9.36
	55.66			6	4.4
				7	1.6
				8	0.32
				9	0.05
					67.54

Table 5. 9: Table showing percent burnt area between 1991-95 & 2000-05

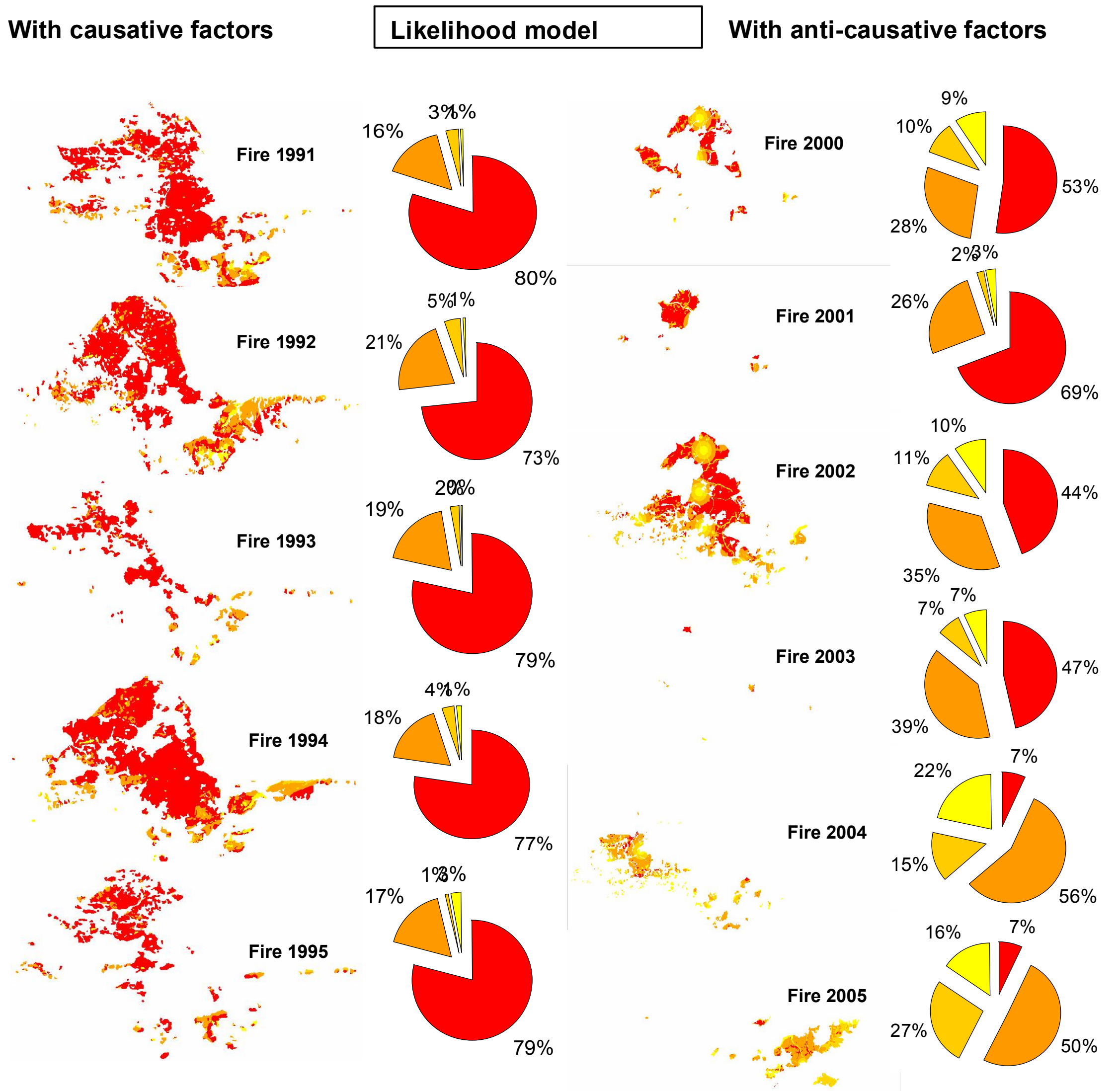


Figure 5. 25: Assessment of the Likelihood model with the fire burnt area (1991-95 & 2000-05)

It is observed that nearly 55% of the study area has been affected by fire between 1991 and 1995. Likelihood model accounts for most of the areas burnt during 1991 and 1995. Majority of the burnt area falls in the extreme category (73-80%). Best fit scenario can also be generated for each year separately from the model.

Between 2000 and 2005, the burnt area falls in both extreme and high category. Even the likelihood model shows reduction in the extreme category (fig 5.25) but burnt area falling in high category is due to the shift in the major causative factor. In 2004 and 2005, new areas got burnt which were never recorded in the last 15 years (Forest department data).

	Burnt area (in %)		
	1991-95	2000-05	1991-05
extreme	73.45	36.75	33.46
high	21.01	38.75	42.10
moderate	1.13	12.80	11.82
low	4.41	11.70	12.62

Table 5. 10: Table showing category wise cumulative burnt area

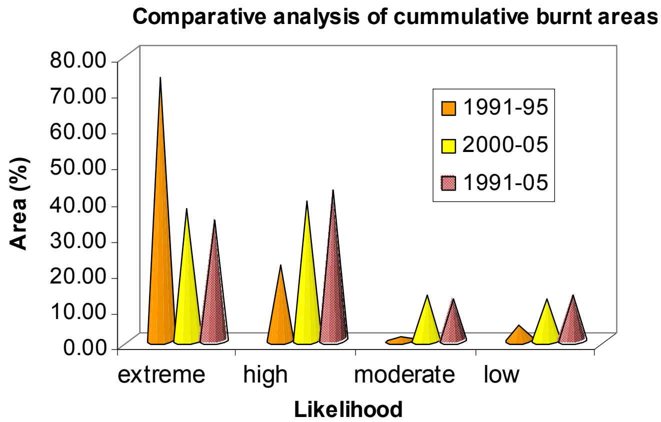


Figure 5. 26: Graph showing total cumulative fire burnt area (1991-2005)

From the cumulative data set, it is evident that nearly 67% of the area has been affected by forest fire between 1991 and 2005 (table 5.9). During the first phase (1991-95) without anti-causative factors, the model accounts for the majority burnt area in the extreme category. It is also seen from the time series data set (1991-95) that extreme category of likelihood ness of the fire is nearly 74%. In second phase (2000-05), there is reduction in the cumulative burnt area, maybe due to the anti-causative factors. The burnt area falls in both extreme and high category. The high category is due to the new area (1 time-39%) getting burnt mainly in 2004 & 2005.

	Burnt area (in %)					
	1991-95		2000-05		1991-05	
	All Occur	Reg. Occur	All Occur	Reg. Occur	All Occur	Reg. Occur
extreme	73.45	78.91	36.75	40.96	33.46	41.26
high	21.01	17.28	38.75	34.34	42.10	39.83
moderate	1.13	0.74	12.80	13.86	11.82	9.34
low	4.41	3.07	11.70	10.84	12.62	9.57

Table 5. 11: Table showing category wise cumulative burnt area of regular occurrences

If we consider the regular fire occurrences (excluding 1 time occurrence) between 1991 and 2005, it is evident that nearly 75-80% of the burnt area falls in the extreme and high categories in accordance to the developed likelihood model.

5.4.8. Calibration and Validation of the Likelihood model

It is observed that the existing model still can be calibrated and fine tuned to account for certain deviations in the result as analysed above. We need to generate different scenarios and see the best fit of the cumulative fire burnt data (1991-2005).

Statistics happens to be an important tool which helps in calibration and validation of the model along with robustness of the model. Inferential statistics use information from a sample to infer about the field situation or to test a hypothesis. Parametric statistics can be used when the factors can be assumed to have known distribution. Since standard deviation is usually unknown, a t-distribution based on the sample is substituted for the normal or bell-shaped distribution. The shape of the distribution depends on the size of the sample i.e. larger the sample size, closer the t-distribution to the normal distribution (Huntsberger & Billingsley, 1977). An assumption about the sample is that it has normal distribution and is independent of each other. To ensure that the assumption is met, it is important to have the random sample set. The situation which needs to be ameliorated is to predict the changes in one factor as other factors change. This type of situation is settled statistically by the use of regression analysis using linear regression (one dependent and one independent variable) or multiple linear regression (one dependent and many independent variables). Regression analysis uses associations between the dependent and independent variables to construct an equation describing the dependent variable based on the independent variables.

In the current study, 80 random sample points have been considered in the reference image which relates to the ground data of cumulative fire from 1991-2005 (fig 5.27). The data has been classified into 3 classes as under:

1 – low (unburnt)

2 – medium (burnt 1 time)

3 – high (burnt > 1 time)

Similarly, the data in likelihood model has been reclassified by merging low and moderate into a single category as low, high as medium and extreme as high.

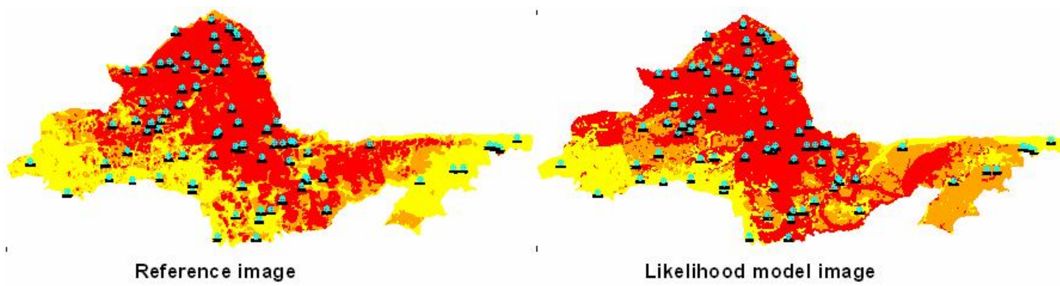


Figure 5. 27: Reference & Likelihood images overlaid with random sample points

Regression Statistics	
Multiple R	0.787907184
R Square	0.620797731
Adjusted R Square	0.615936164
Standard Error	0.502249526
Observations	80

Table 5. 12: Table showing Regression statistics for the Likelihood model

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	32.21164	32.21164	127.695	4.27E-18
Residual	78	19.67586	0.252255		
Total	79	51.8875			

Table 5. 13: Table showing ANOVA for the Likelihood model

	Coeff	*SE*	*t Stat*	*P-value*	*Lr 95%*	*Up 95%*	*Lr 95.0%*	*Up 95.0%*
Intercept	0.6857	0.1669	4.1073	9.79E-05	0.3533	1.0181	0.3533	1.0181
X Variable	0.7364	0.0651	11.300	4.27E-18	0.6067	0.8662	0.6067	0.8662

Table 5. 14: Table showing Coefficient, SE, t-stat and P-value for the Likelihood model

In the Regression statistics (Table 5.12), we can see the linear regression analysis by "least square" method to fit a line through a set of observations. We can analyze how a single dependent variable is affected by the value of one or more independent variables. Correlation is closely associated with the regression analysis and determines the degree of association between the factors. A correlation coefficient (r) approaching 1 indicates high positive association between the two variables. Even though, the two variables may be highly correlated, this may not necessarily mean one as a good predictor of the other. Multiple regressions can be useful in choosing which independent variables can be useful in the prediction, by testing the coefficients of each variable (table 5.14). The most common statistics employed to compare the means of two samples is the t-test. The test assumes that one has a normal distribution and the other has a t-distribution. However, Analysis of Variance (ANOVA) provides a different type of variance analysis. This technique expands on the tests for two means, such as the t-test. In the current data set, ANOVA performs a simple analysis of variance, testing the hypothesis that means from two or more samples are equal (table 5.13). In the suggested Likelihood model, Multiple-R of 0.7879, F-value of 127.695 and P-value of 0.0000979 is considered quite significant and suggests positive correlation with the ground situation. The Rank and Percentile analysis produces a table that contains the ordinal and percentage rank of each value in the data set. We can analyze the relative standing of values in the data set (fig 5.28).

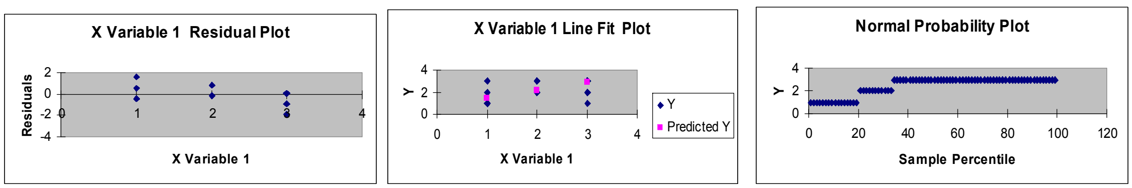


Figure 5. 28: Graphs showing Residual, Line Fit and Normal Probability Plots

To make model more robust it is necessary to evaluate the effect of each independent variable (causative factor) in this case with the reference data (cumulative burnt areas). It is assumed that with the dropping of any variable from the data set of the model, there should be reduction in the linear regression and correlation (fig 5.29 & table 5.15).

SUMMARY - INFLUENCE OF INDEPENDENT VARIABLES ON THE MODEL						
	Likelihood	No antler	No poach.	No tourism	No grazing	No encl/est/vill
Multiple R	**0.78791**	0.62623	0.66271	0.74433	**0.79877**	0.78791
R Square	**0.62080**	0.39216	0.43918	0.55402	**0.63803**	0.62080
Adjusted R Sq.	**0.61594**	0.38437	0.43199	0.54830	**0.63339**	0.61594
Standard Error	**0.50225**	0.67338	0.60436	0.55334	**0.49967**	0.50225
Coefficient	**0.73648**	0.61987	0.61292	0.70680	**0.76026**	0.73648
F-value	**127.69497**	50.32374	61.08242	96.89646	**137.48493**	127.69497
P-value	**0.00010**	0.00276	0.00058	0.00019	**0.00039**	0.00010

Table 5. 15: Statistics showing Influence of independent variables vis-à-vis Likelihood model

From the above statistics (table 5.15) it is evident that each independent variable has an effect on the suggested likelihood model in terms of regression, correlation and ANOVA. Antler factor has the maximum influence on the suggested Likelihood model when compared with the other factors. There is no influence of the demographic factors like enclave, estate and village. But it is seen that grazing factor has a reverse influence pointing to the fact that the suggested model in question is not the best fit and can be further corrected.

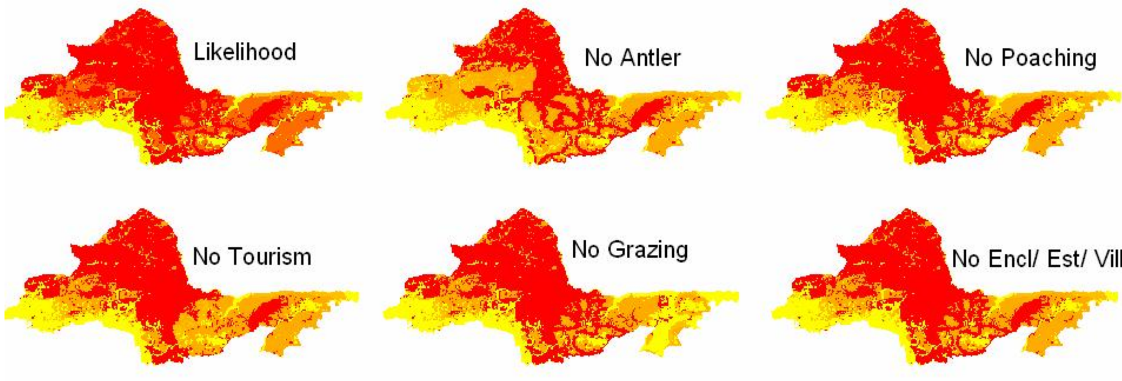


Figure 5. 29: Influence of independent variables on the Likelihood model

Calibration in the grazing factor has been carried out in terms of flammability of the habitat in the grazing zone. It has also been observed that the grass availability in the grazing zone is quite restricted due to the thorny/ scrubby nature of the forest. Therefore, high and extreme conditions of the causative factor in the (moderate) grazing habitat may lead to moderate fire when compared to the other habitats (fig 5.30).

Changes in parameters of Grazing factor				
	Factor (Y)	Habitat (X)	Output (O)	Output (S)
G1	High	Mod	High	Mod
G2	Ext	Mod	Ext	Mod

Table 5. 16: Calibration in the Grazing factor

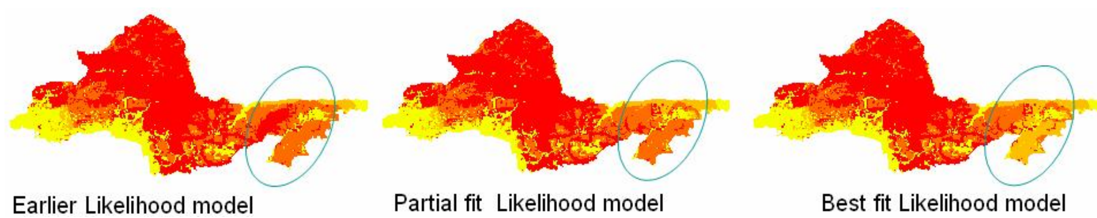


Figure 5. 30: Calibration of the model for best fit Likelihood model

SUMMARY - INFLUENCE OF GRAZING VARIABLE ON THE MODEL		
	Earlier Likelihood	**Best fit**
Multiple R	0.78791	**0.79877**
R Square	0.62080	**0.63803**
Adjusted R Square	0.61594	**0.63339**
Standard Error	0.50225	**0.49967**
Coefficient	0.73648	**0.76026**
F-value	127.69497	**137.48493**
P-value	0.00010	**0.00000**

Table 5. 17: Statistics showing Influence of Grazing factor vis-à-vis Likelihood model

As evident from the table 5.17, calibration of the grazing factor has led to the improvement in the Likelihood model. There is increased regression and correlation in the Multiple-R, Correlation coefficient and F-value with the associated reduction in the P-value. This depicts significantly in the model. Besides statistical validation, we can also re-run the model on the time series data set as carried out in 5.4.7, to assess the significance of the best fit.

5.4.9. Sensitivity Analysis

Sensitivity analysis is the process of varying model input parameters over a reasonable range and observing the relative change in model response. The observed changes in the different categories of the model are noted. The purpose of the sensitivity analysis is to demonstrate the sensitivity of the model simulations to uncertainty in values of model input data. Such knowledge is important for (a) evaluating the applicability of the model, (b) determining parameters for which it is important to have more accurate values, and (c) understanding the behavior of the system being modeled. The sensitivity of one model parameter relative to other parameters has also been considered. Sensitivity analysis is also beneficial in determining the direction of future scenario as well as planning management interventions. Data for which the model is relatively sensitive would require future characterization, as opposed to data for which the model is relatively insensitive. Model-insensitive data would not require further field characterization.

The choice of a sensitivity analysis method depends to a great extent on (a) the sensitivity measure employed, (b) the desired accuracy in the estimates of the sensitivity measure, and (c) the computational cost involved. Table 5.18 presents some of the sensitivity measures that are often employed in the sensitivity analysis of a mathematical model of the form

$$F(u,k) = 0$$

where k is a set of m parameters, and u is a vector of n output variables.

Summary of sensitivity measures employed in sensitivity analysis	
Sensitivity Measure	**Definition**
Response from arbitrary parameter variation	$u = u(\bar{k} + \delta k) - u(k)$
Normalized Response	$D_i = \frac{\delta u_i}{u_i(\bar{k})}$
Average Response	$\overline{u_i(\bar{k})} = \frac{\int u_i(\bar{k})dk}{\int dk}$
Expected Value	$\langle u_i(k) \rangle = \int u_i(kP(k)dk$
Variance	$\delta_i^2(k) = \langle u_i(k)^2 \rangle - \langle u_i(k) \rangle^2$
Extrema	$\max[u_i(k)], \min[u_i(k)]$
Local Gradient Approximation	$\delta u \approx [S]\delta k; S_{ij} = \frac{\partial u_i}{\partial k_j}$
Normalized Gradient	$S_{ij}^n = \frac{\bar{k}_j}{u_i(\bar{k})} \frac{\partial u_i}{\partial k_j}$

Table 5. 18: Sensitivity measures employed in analysis (adapted from McRae et al., 1982)

Based on the choice of sensitivity metric and the variation in the model parameters, sensitivity analysis methods can be broadly classified into the following categories:

Variation of parameters or model formulation: In this approach, the model is run at a set of sample points (different combinations of parameters of concern) or with straightforward changes in model structure. Sensitivity measures that are appropriate for this type of analysis include the response from arbitrary parameter variation, normalized response and extrema. Of these measures, the extreme values are often of critical importance in environmental applications.

Domain-wide sensitivity analysis: Here, the sensitivity involves the study of the system behaviour over the entire range of parameter variation, often taking the uncertainty in the parameter estimates into account.

Local sensitivity analysis: Here, the focus is on estimates of model sensitivity to input and parameter variation in the vicinity of a sample point. This sensitivity is often characterized through gradients or partial derivatives at the sample point.

In the suggested Forest Fire Likelihood model, sensitivity analysis is carried out by changing the parameters in the model structure to check for changes in the extreme values. This also depicts the robustness of the model. The model is taken as the reference and regression analysis including correlation coefficient is performed to check for the robustness and sensitivity of the model to the changed parameters. Changes in the parameters are performed in the individual variables (fig 5.31) as well as in combination (fig 5.32).

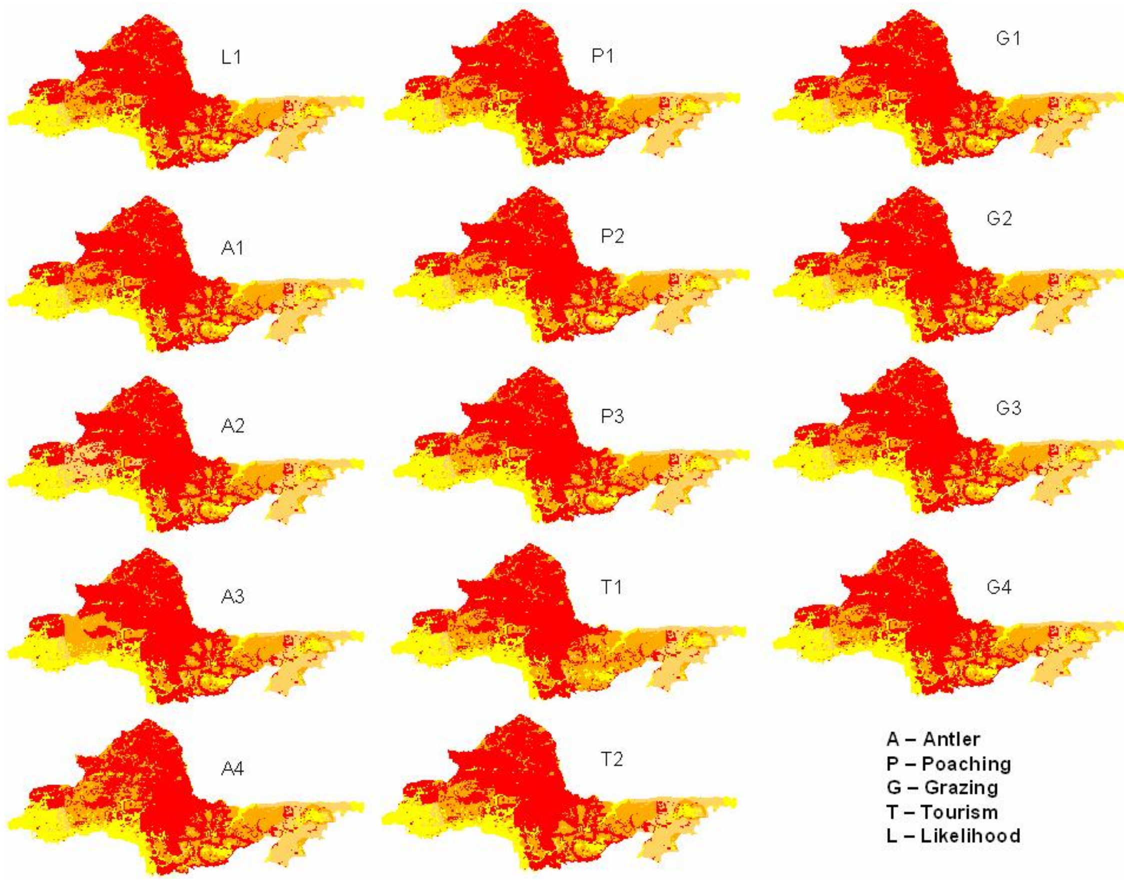


Figure 5. 31: Sensitivity analysis for changes in parameters of individual variable

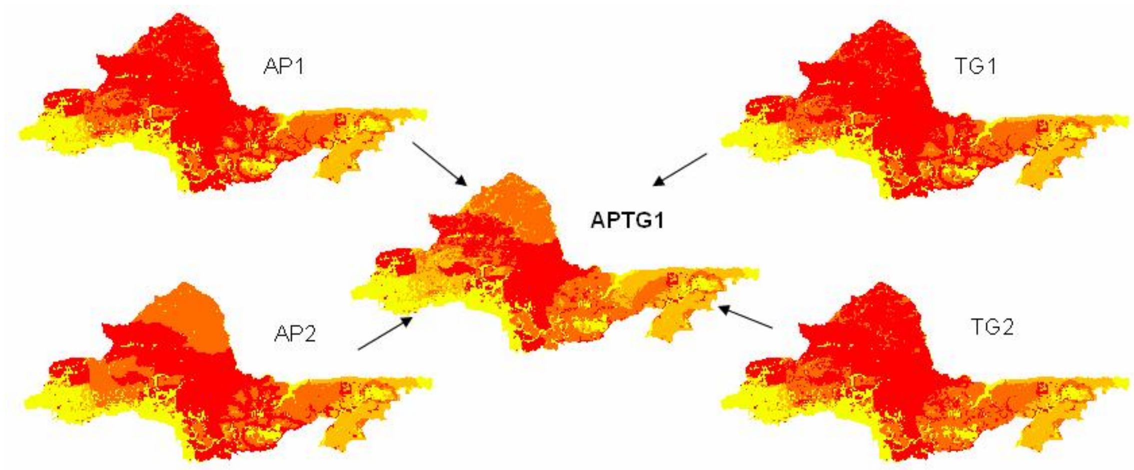


Figure 5. 32: Sensitivity analysis for changes in parameters of variables in combination

Changes in parameters of individual variable					
	Factor (Y)	Habitat (X)	Output (O)	Output (S)	**Change**
A1	Low	Ext	High	Mod	Not significant
A2	Mod	High	High	Mod	Not significant
A3	Mod	Ext	Ext	High	Not significant
A4	High	High	Ext	High	Not significant
P1	Low	Ext	High	Mod	Not significant
P2	Mod	High	High	Mod	Not significant
P3	Mod	Ext	Ext	High	Not significant
T1	High	Ext	Ext	High	Not significant
T2	Ext	High	Ext	High	Not significant
G1	Mod	High	High	Mod	Not significant
G2	High	Ext	Ext	High	Not significant
G3	Ext	High	Ext	High	Not significant
G4	Ext	Mod	Mod	High	Not significant

Table 5. 19: Sensitivity measures employed in analysis of individual variable

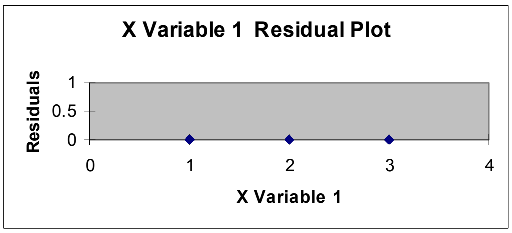
Changes in parameters of variables in combination					
	Factor (Y)	Habitat (X)	Output (O)	Output (S)	**Change**
AP1	Low	Ext	High	Mod	Not significant
AP2	Mod	Ext	Ext	High	Partial
TG1	High	Ext	Ext	High	Partial
TG2	Ext	High	Ext	High	Not significant
APTG	-	-	-	-	Partial

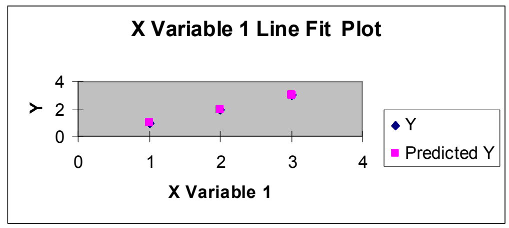
Table 5. 20: Sensitivity measures employed in analysis of variables in combination

From the above figs and tables, it is quite evident that when the changes in the model structure are undertaken (both in individual variable as well as in combination), the change in the generic output of the model is not very significant. With the change in the individual variable, the change is negligible whereas when conducted in combination, the change is partial. Basically, the partial change is quite restricted and the movement is from extreme to high category in the regular fire burnt areas whereas high to moderate in the infrequent fire sensitive areas.

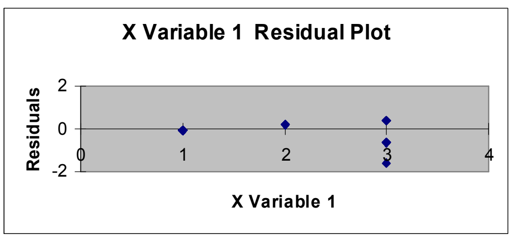
INFLUENCE OF INDEPENDENT VARIABLES ON THE SENSITIVITY OF THE MODEL						
	Likelihood	AP1	AP2	TG1	TG2	APTG
Multiple R	-	1	0.829790	1	0.981838	0.780814
R Square	-	1	0.688552	1	0.964005	0.609670
Adjusted R Sq.	-	1	0.684559	1	0.963544	0.604666
Standard Error	-	0	0.438644	0	0.157199	0.514453
Coefficient	-	1	0.785316	1	0.979554	0.774164

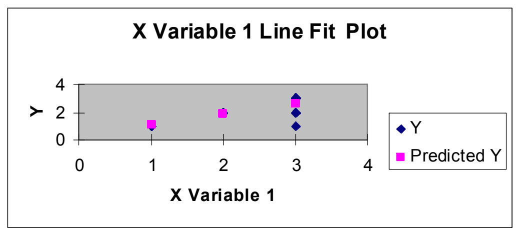
Table 5. 21: Statistical analysis for variables in combination on sensitivity of the model



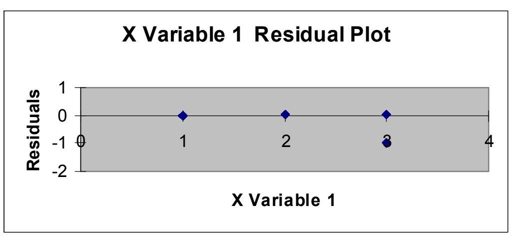


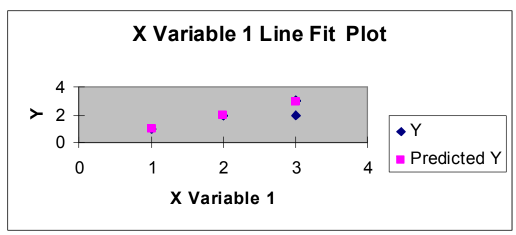
Antler-Poaching/ Tourism-Grazing factor variation - moderate (AP1/TG1)



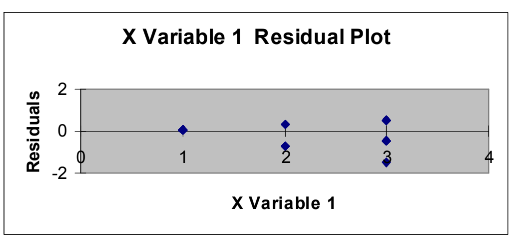


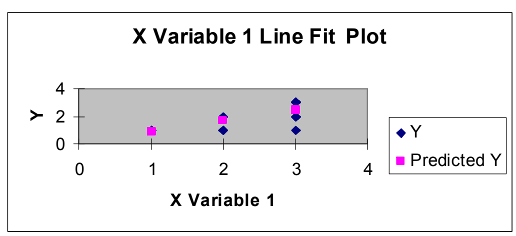
Antler-Poaching factor variation - high (AP2)





Tourism - Grazing factor variation - high (TG2)





All factors variation - high (APTG)

Figure 5. 33: Sensitivity analysis for changes in parameters of variables in combination

From the above statistical analysis, it is evident that the model is insensitive to moderate changes in the parameters of all variables. However, with high variation in the parameters of critical variables, the model shows partial departure from one category to the other in certain areas. The change is still within the statistical limits as reflected by significant values of regression and correlation coefficient. The above model can be considered as fairly robust and generic for the study area.

5.5. Implementation of Evaluation models

The evaluation models have been developed from the perspective of planning and evaluating management interventions. As the infrastructure and resources are limited, the evaluation models developed for area value and mitigation strategy become highly significant. There could be areas which are frequently getting burnt but may not be very significant from the perspective of area value or vice versa.

5.5.1. Identification of Area Value parameters

The input variables in the Area value evaluation model has been generated by the cross of habitat (flammability) map with the area value map (fig 5.34). The area value has been identified in accordance to the proposed methodology for the ecological, economic and social values. The ecological value is comprised of geomorphic (catchment & rocky gorge) and biological (wetland & wildlife) values. The economic value comprises of teak plantation (Annex 5.3) and vegetation values (Annex 5.4 & 5.5). The social value comprises of grazing and recreational values which has been computed as per the available zonation.

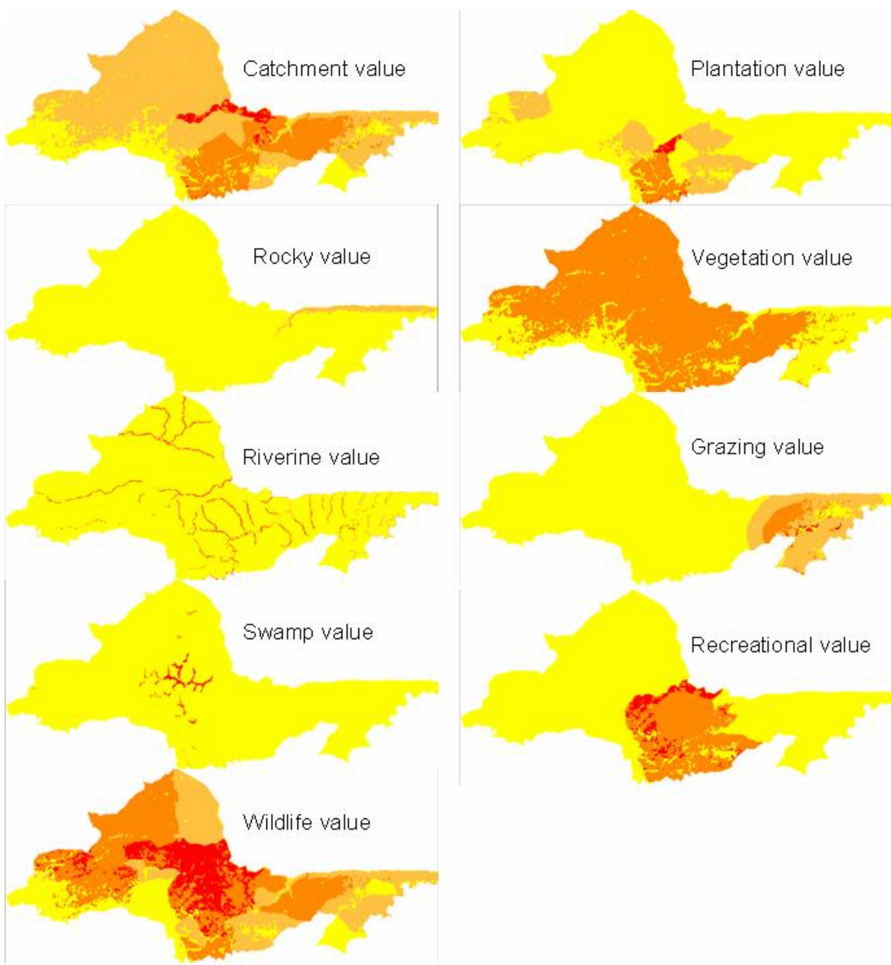
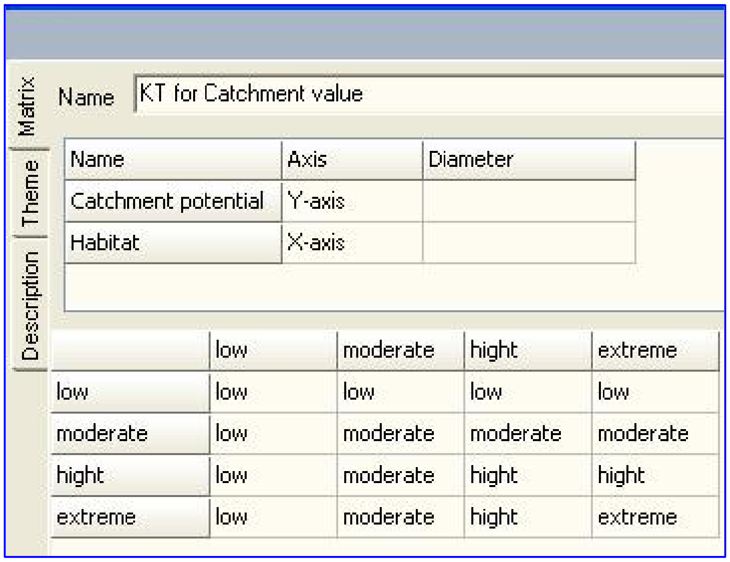


Figure 5. 34: Variables related to the Area value

Quantification of the area value has been carried out as per the spatial extent of that value and the same has been normalized on the ordinal scale to depict the four categories.

5.5.2. Generation of Area Value matrix

Area value matrix connects to one or more system attributes and is visualized in the form of a table (fig 5.35). Every dimension is in conformity with a theme and outcome is also based on a theme. It has been represented in the form of classes (low, moderate, high and extreme) with value in the form of a colour.



Matrix | Theme | Description

Name: KT for Catchment value

Name	Axis	Diameter
Catchment potential	Y-axis	
Habitat	X-axis	

	low	moderate	hight	extreme
low	low	low	low	low
moderate	low	moderate	moderate	moderate
hight	low	moderate	hight	hight
extreme	low	moderate	hight	extreme

Figure 5. 35: Generation of Area value matrix

5.5.3. Prioritization of Area Value

The prioritization of the area value is carried out as per the *Overlay* approach to obtain the ecological and socio-economic values and finally the Area value. It is observed that with the cross of habitat (flammability) map with the Area value map, we are able to generate the total area value (TIV) from the perspective of fire likelihood (fig 5.36).

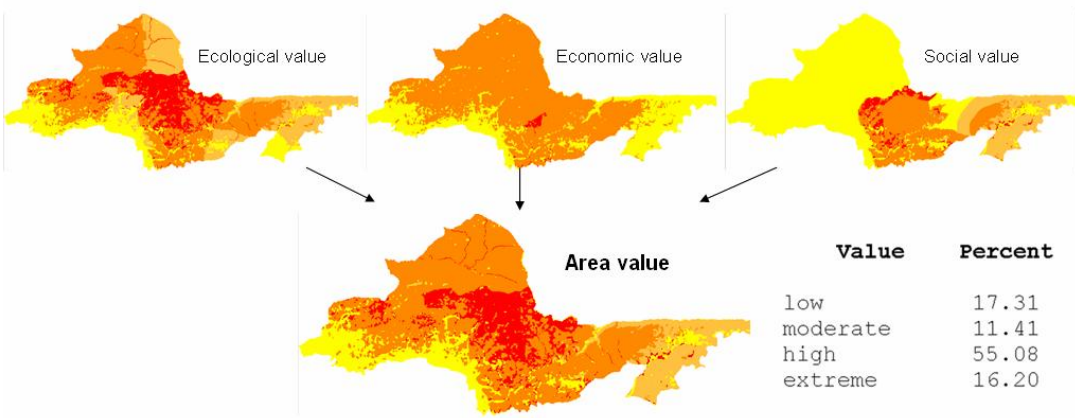
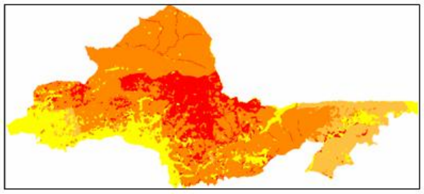
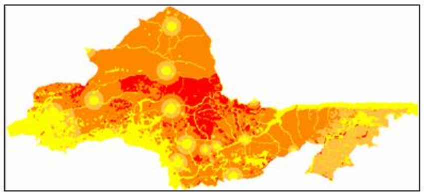


Figure 5. 36: Prioritized Area value

It is evident that nearly 16% of the study area has extreme value which needs to be considered first in terms of management intervention followed by the high category. The extreme category of area value is also significant in terms of regular fire incidences. We can always evaluate the likelihood model both with causative and anti-causative factors as well as fire burnt areas (1991-2005) in terms of area value (figs 5.37 & 5.38).

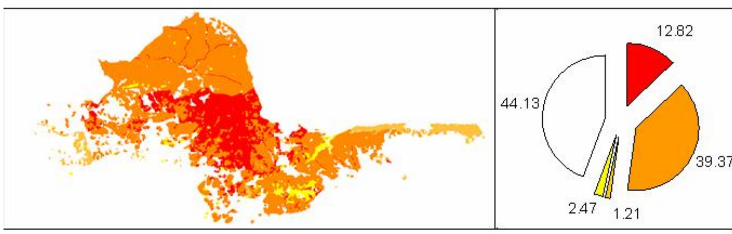


Value	Percent
Low	18.71
Moderate	11.13
High	54.33
Extreme	15.83

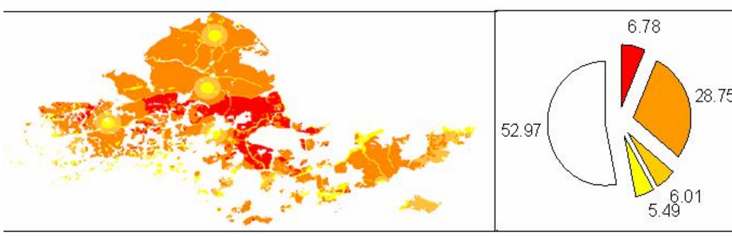


Value	Percent
Low	25.81
Moderate	15.46
High	48.21
Extreme	10.52

Figure 5. 37: Likelihood model vis-à-vis Area value



Category	Without Area Value (%)	With Area Value (%)
Extreme	41.05	12.82
High	11.74	39.38
Moderate	0.63	1.21
Low	2.46	2.47
Unburnt	44.12	44.12



Category	Without Area Value (%)	With Area Value (%)
Extreme	17.28	6.78
High	18.23	28.75
Moderate	6.02	6.01
Low	5.50	5.49
Unburnt	52.97	52.97

Figure 5. 38: Likelihood model assessment with and without Area value

In the above figs, it is observed that as per the Likelihood model (with causative & anti-causative factors) there is reduction in the extreme & high categories and related increase in the low and moderate categories. Similar results are seen in the fire burnt areas, where most of the burnt areas lie as per the model.

5.5.4. Identification of Mitigation parameters

The various mitigation strategies can be evaluated by considering the zone of influence of each management intervention. This can be evaluated in terms of existing management interventions and the proposed interventions.

In the various interventions, it is seen that anti-poaching/ fire camps act as the major deterrent in the likelihood of the fire. The location of such camps in the strategic location can play an effective role in the reduction of the extreme likelihood ness. This is mainly due to the presence of personnel and daily patrolling by the camp staff. It is also observed that the riverine factor also contributes significantly as a management intervention in its vicinity due to the water conservation measures in the study area. The other manned feature i.e. staff quarter/ check post doesn't contribute so significantly, maybe because of its location and other tasks assigned. The other unmanned structures, especially fireline, play a significant role in checking fire spread in the other area but has a limited role in prevention.

Management intervention (%)				
	extreme	high	moderate	low
AP/F camp	80.30	10.60	6.70	2.40
SQ/C post	95.37	2.5	1.62	0.51
Fireline	97.85	0.11	0.14	1.9
Riverine	92.15	2.32	2.34	3.19
FW/Tower	99.38	0.33	0.21	0.07
Checkdam	99.75	0.14	0.08	0.03

Table 5. 22: Zone of influence of various management interventions

5.5.5. Generation of Mitigation strategy matrix

The generation of matrix for mitigation strategy can be visualized in terms of habitat (flammability) and area value.

Management intervention with habitat				
	extreme	high	moderate	low
AP/F camp	27.88	36.98	16.24	18.90
SQ/C post	34.04	35.98	12.36	17.62
Fireline	34.23	35.49	11.30	18.98
Riverine	32.35	36.03	12.25	19.37
FW/Tower	34.68	36.41	11.53	17.38
Checkdam	34.82	36.40	11.45	17.33
Management intervention with Area value				
	extreme	high	moderate	low
AP/F camp	12.81	51.02	15.89	20.29
SQ/C post	15.15	53.75	12.08	19.02
Fireline	15.38	53.22	11.00	20.39
Riverine	14.10	53.23	12.04	20.64
FW/Tower	15.65	54.30	11.28	18.76
Checkdam	15.76	54.31	11.18	18.72

Table 5. 23: Zone of influence of various management interventions with habitat & area value

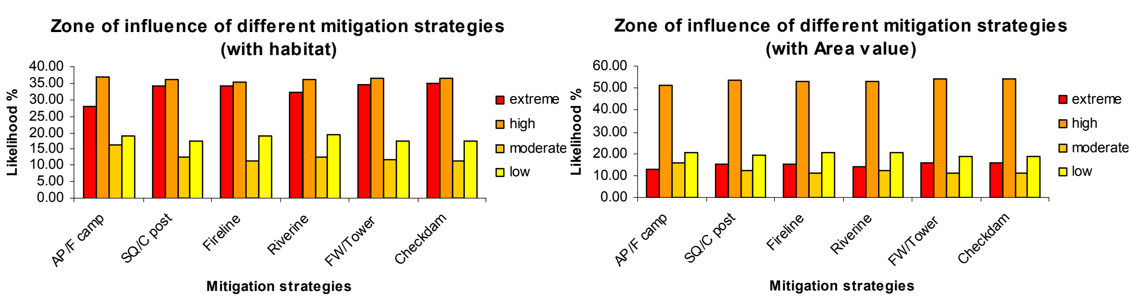


Table 5. 24: Zone of influence of various management interventions with habitat & area value

If we see the effect of various management interventions with respect to habitat (condition of flammability) and Area value, it is evident that the results are same as described earlier.

5.5.6. Prioritization of Mitigation strategy

Prioritization of the mitigation strategy has been carried out by development of grids of 1km x 1km as depicted in fig 5.39. The management interventions are evaluated in terms of location of the various management interventions vis-à-vis likelihood model with area value. The existing interventions are prioritized first at the beat level (administrative unit), then at the compartment level (management unit) and finally location is identified at the grid level (location).

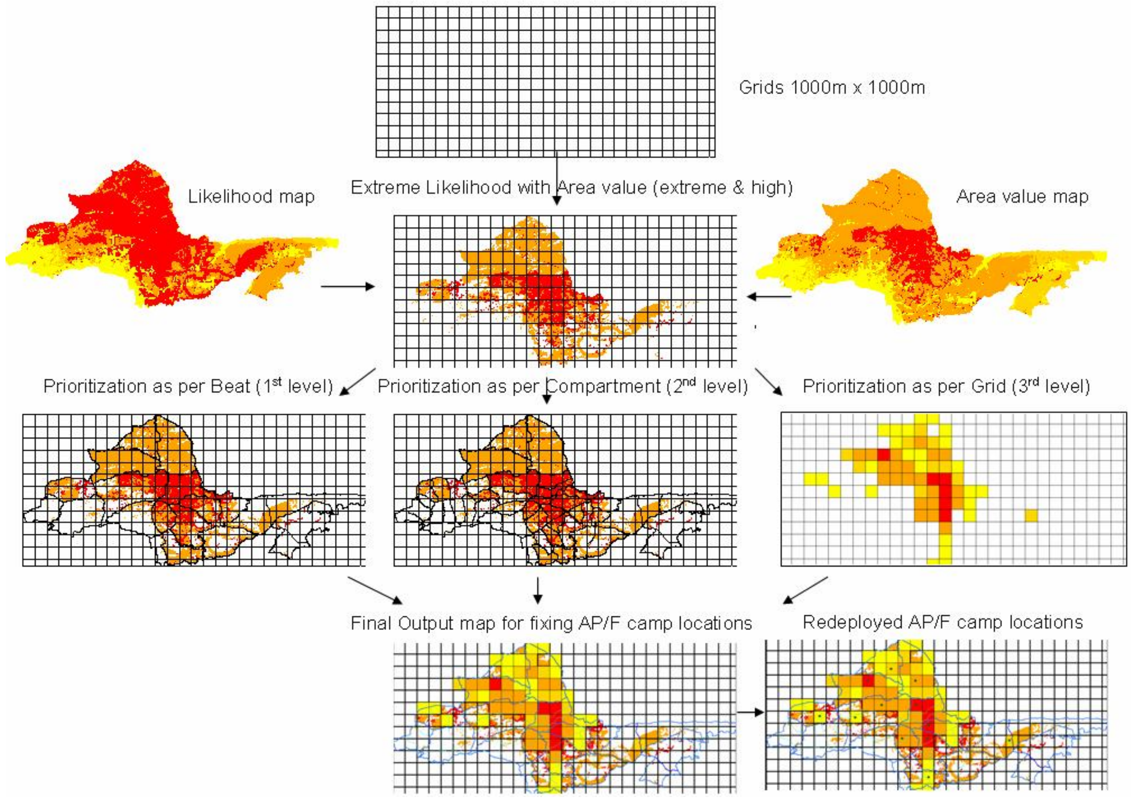


Figure 5. 39: Prioritization of management interventions

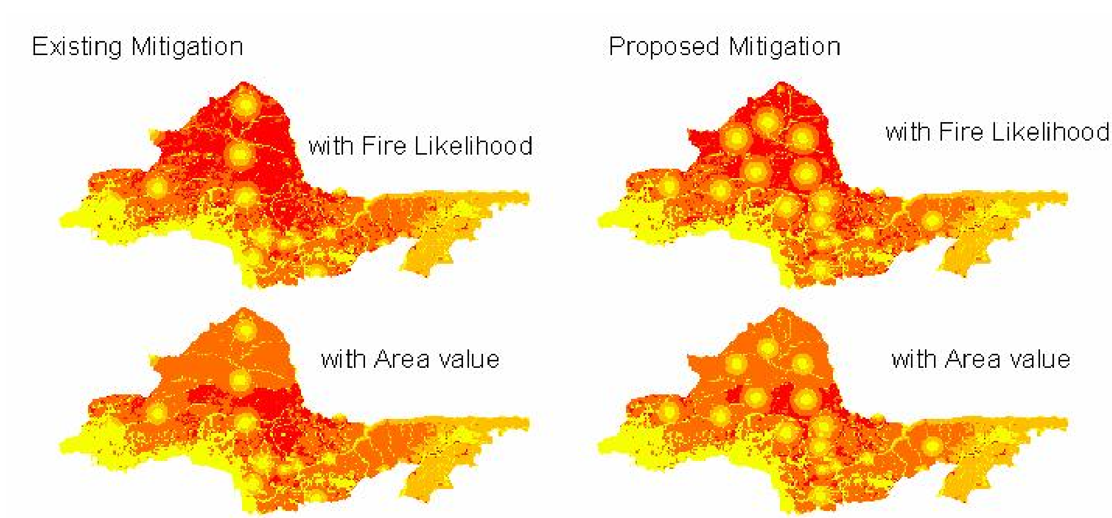


Figure 5. 40: Evaluation of Existing mitigation and redeployment of proposed ones

	Existing Mitigation (%)		Proposed Mitigation (%)	
	Likelihood	Area Value	Likelihood	Area Value
Low	24.05	22.8	24.04	24.04
Moderate	17.19	17.45	20.97	20.97
High	34.31	49.01	37	48.61
Extreme	24.35	10.73	17.99	6.38

Table 5. 25: Evaluation of Existing mitigation and redeployment of proposed ones

Of all the management measures, if we redeploy one of the identified measure i.e. location of antipoaching/ fire camps, we can see the change in the scenario. There appears drastic reduction in the extreme category of likelihood of fire. The redeployment has been suggested on the basis of likelihood map generated as a result of various causative factors. We can also plan any deletion or addition of management intervention as per the model.

5.5.7. Assessment of Management interventions for fire data (1991-2005)

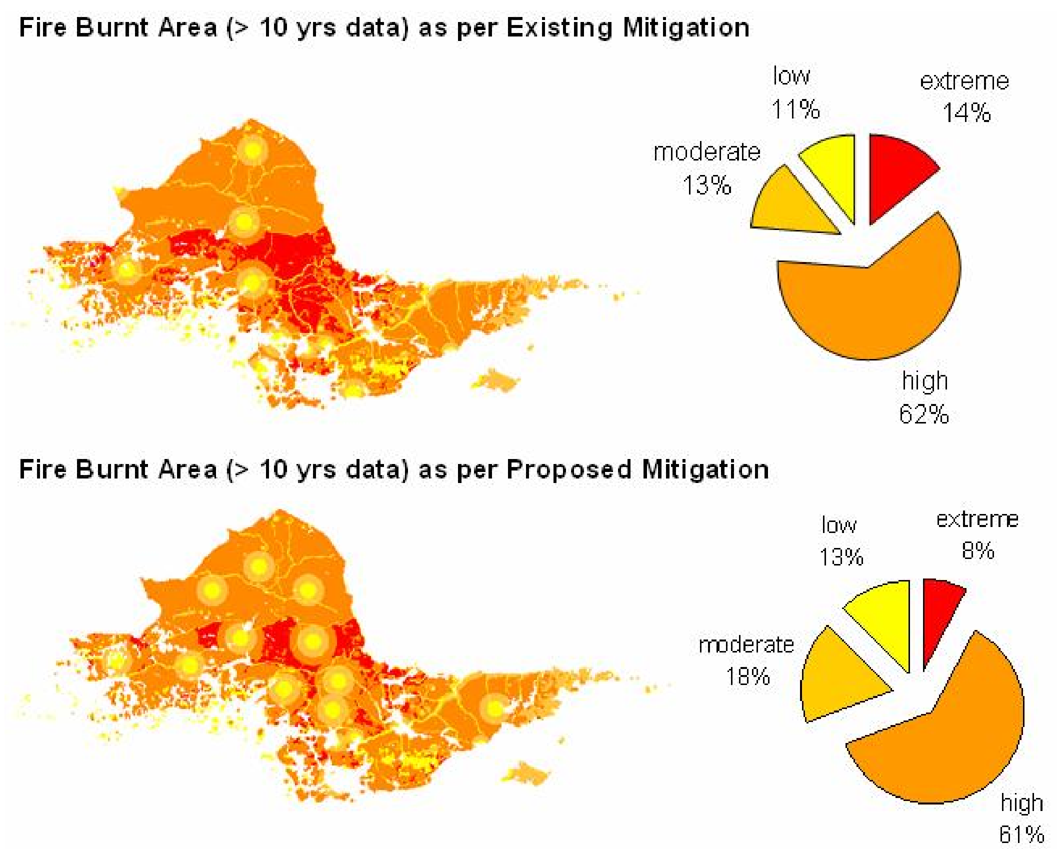


Figure 5. 41: Evaluation of mitigation measures as per fire burnt areas

From the fig 5.41, it is evident that the redeployment of anti-poaching/fire camps as per the suggested mitigation could help in further reduction of the extreme category of likelihood of fire and related amelioration towards lower and moderate likelihood.

5.6. GIS Customization using Map Objects

5.6.1. Interactive Visualization

A map is a repository of information about geographic data in terms of location, spatial relationships and attributes. We can examine the information in our data by analysing the tables associated with the data sets and running the spatial and non-spatial queries. We can also conduct detailed analysis by making necessary amends in the maps and see the related changes.

5.6.1.1. Development of Customized Front Page

The front page has been developed with the objective of providing user with an easy perception of the project and access to the various scenarios (fig 5.42 & 5.43).

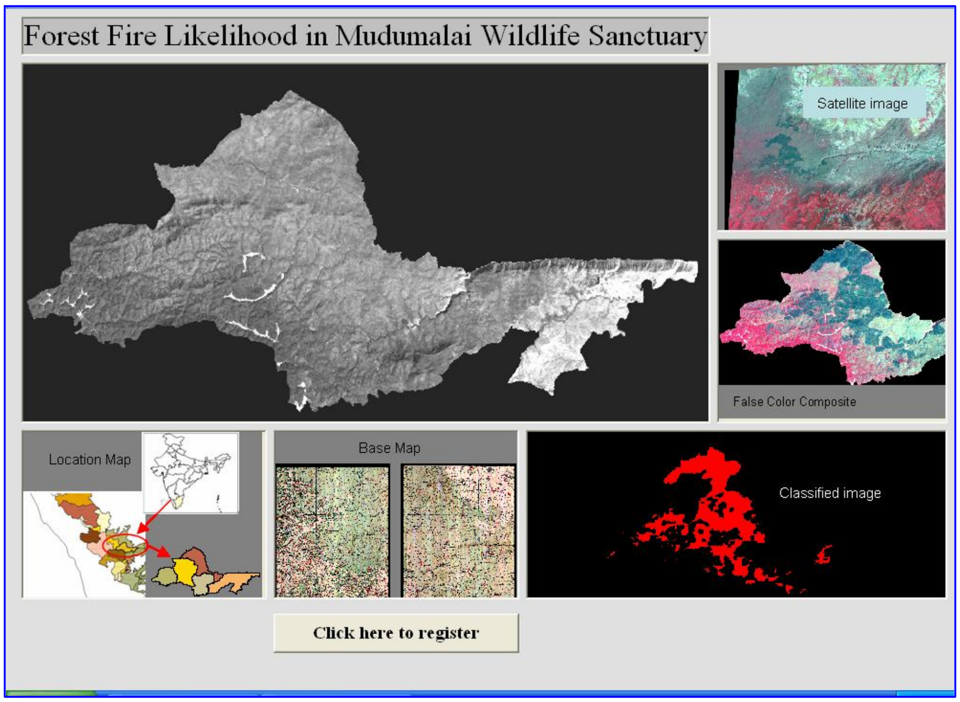


Figure 5. 42: Front page of the GIS customization

Figure 5. 43: Project team and Project objective

The project objective spells out the details on causative and anti-causative factors, fire likelihood, area value and mitigation strategy. The scenario and data can be accessed by entering into the specific theme.

5.6.1.2. Customization of Causative & Anti-causative factors

The customized page has been developed for the various causative as well as anti-causative factors. We can get the spatial distribution on the map as well as quantification in terms of extent of coverage (in sq. metres and percent). The query can be run for the retrieval of both spatial as well as non-spatial data. We can generate the scenarios of extreme, high, moderate and low situations either by *option click* or by *typing* in the option box. We can also zoom, pan or refresh the map. All the scenarios are displayed as a flash layer. The customized page also offers for the detailed analysis through different GIS software and we can do the necessary analysis & corrections and again have an access to the modified scenario (figs 5.44 & 5.45). The page has been developed to see the assesment of various causative factors vis-à-vis fire burnt area. As a prototype, analysis has been done for the burnt areas of 1991 (figs 5.46).

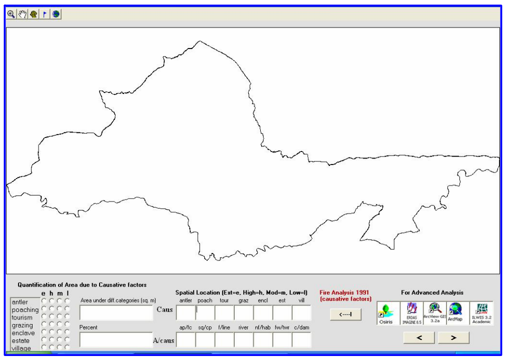


Figure 5. 44: Customization of Causative & Anti-causative factors

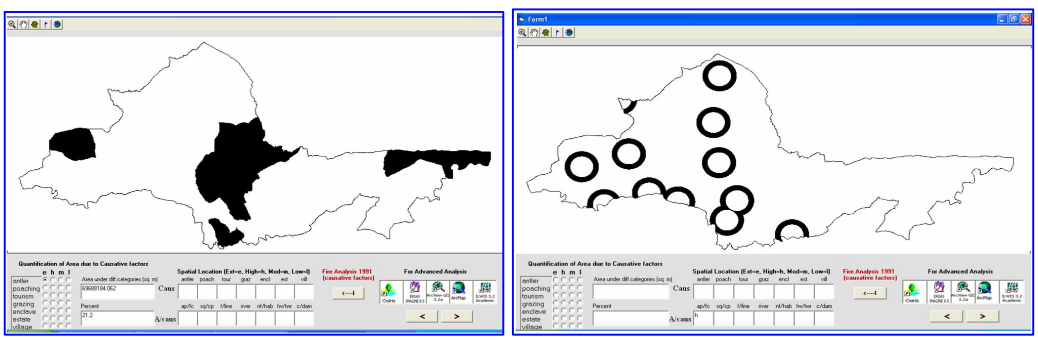


Figure 5. 45: Antler factor (Extreme) &: Anti-poaching/ Fire camp (High)

The fire scenario and validation of causative and anti-causative factors is depicted below:

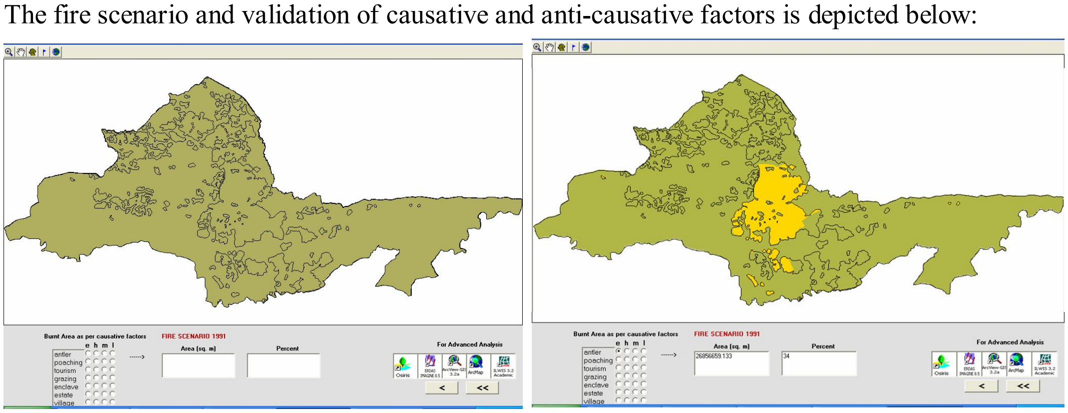


Figure 5. 46: Fire burnt area (1991) & Antler factor (Extreme)

5.6.1.3. Customization of Forest Fire Likelihood

The customized page has been developed for the fire likelihood envisaging all causative and anti-causative factors. Here, we can get the spatial distribution as well as quantification in terms of extent of coverage including different scenarios (fig 5.47). The customized page also offers for the detailed analysis through different GIS software from the customized page itself.

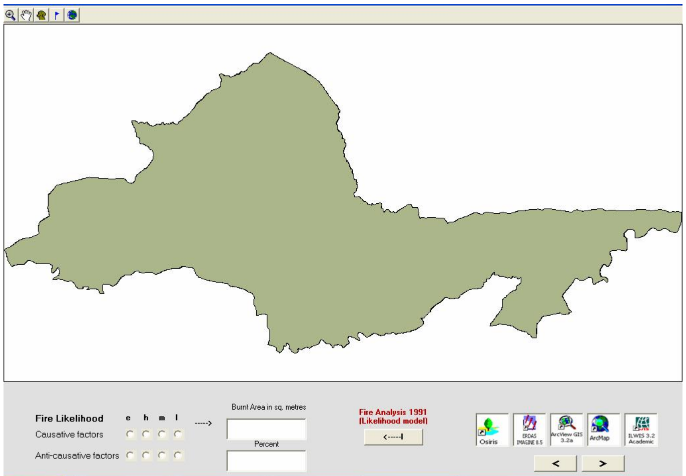


Figure 5. 47: Customization of Fire Likelihood as a result of causative and anti-causative factors

The influence of fire likelihood as a result of cumulative causative and anti-causative factors can be seen (fig 5.48). Similarly, the zone of influence on the burnt area (1991) can also be seen (fig 5.49). We can retrieve both spatial extent as well as related attribute.

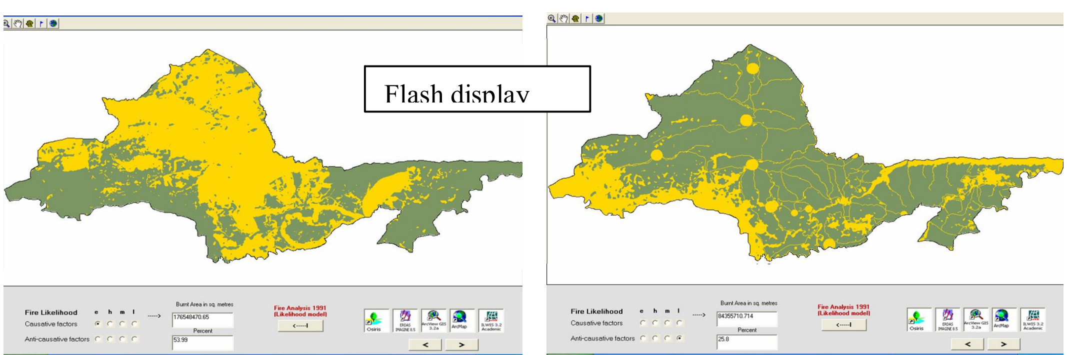


Figure 5. 48: Likelihood - Causative (Extreme) & Anti-causative (Low)

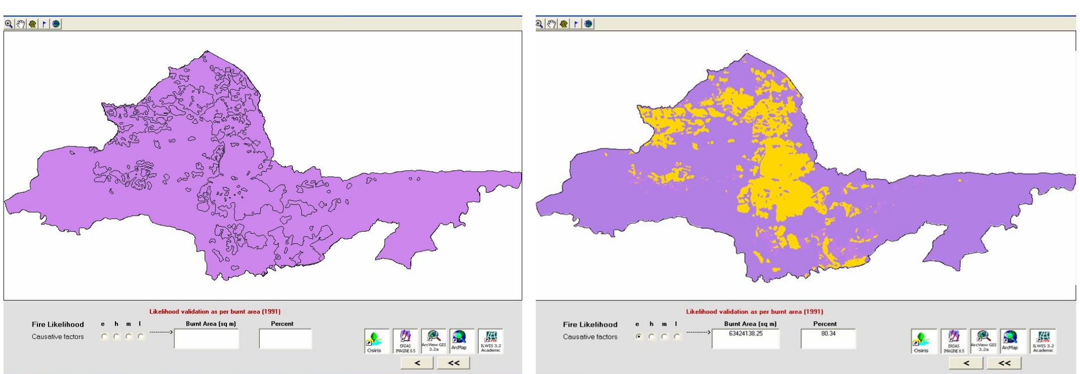


Figure 5. 49: Burnt Area (1991) & Likelihood - Causative (Extreme)

Detailed Analysis

The detailed analysis can be carried out by accessing various GIS software from customized page itself (fig 5.50).

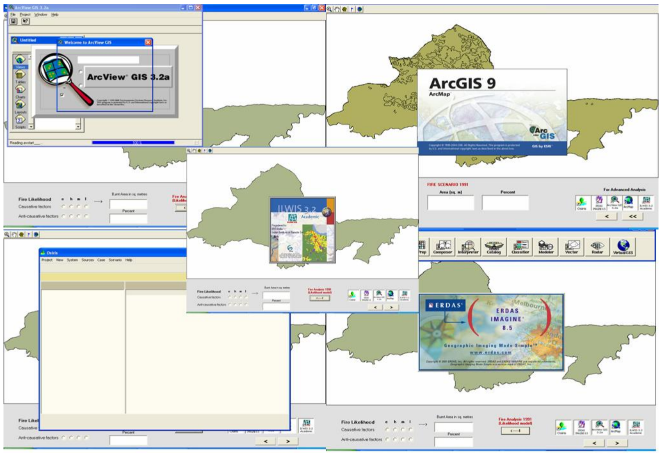


Figure 5. 50: Access through various GIS software in Visual Basic

5.6.1.4. Customization of Area Value

The customized page has been developed for the area value considering ecological, economic and social values (fig 5.51) and the query is displayed as a flash layer (fig 5.52). The influence of fire (1991) as a prototype has been use to display the zone of influence of area value (fig 5.52).

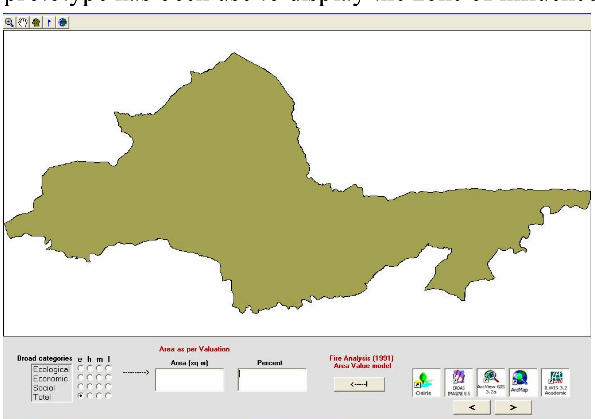


Figure 5. 51: Customization of Area Value envisaging ecological & socio-economic values

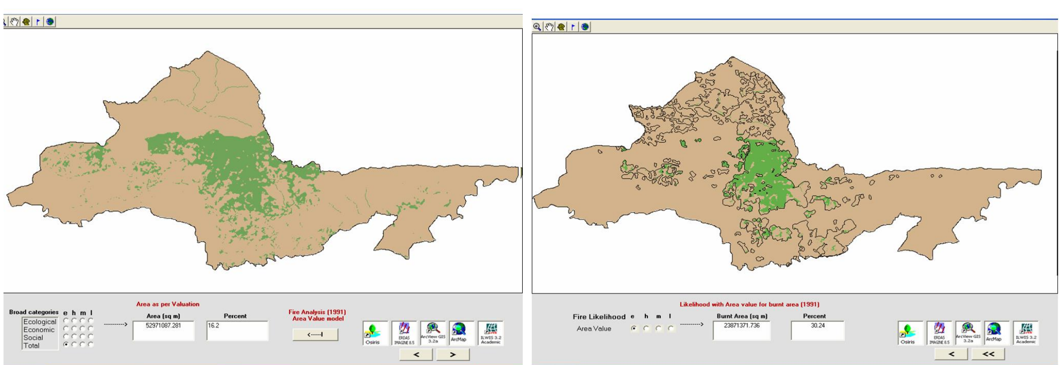


Figure 5. 52: Area Value (Extreme) & Burnt Area 1991 (Extreme value)

5.6.1.5. Customization of Mitigation Strategy

The customized page for mitigation strategy highlights both existing mitigation as well as proposed mitigation. The existing mitigation envisages mainly anti-causative factors. All the layers are included as map layers and the zone of influence of each layer can be retrieved (fig 5.53). As a prototype, burnt area (1991) has been used to depict the effect of proposed mitigation by redeployment of anti-poaching/ fire camp locations (fig 5.54). The result can be observed in terms of reduction of extreme category (figs 5.55). Such customized outputs can be effectively utilized in planning mitigation and seeing the effectiveness of existing mitigation.

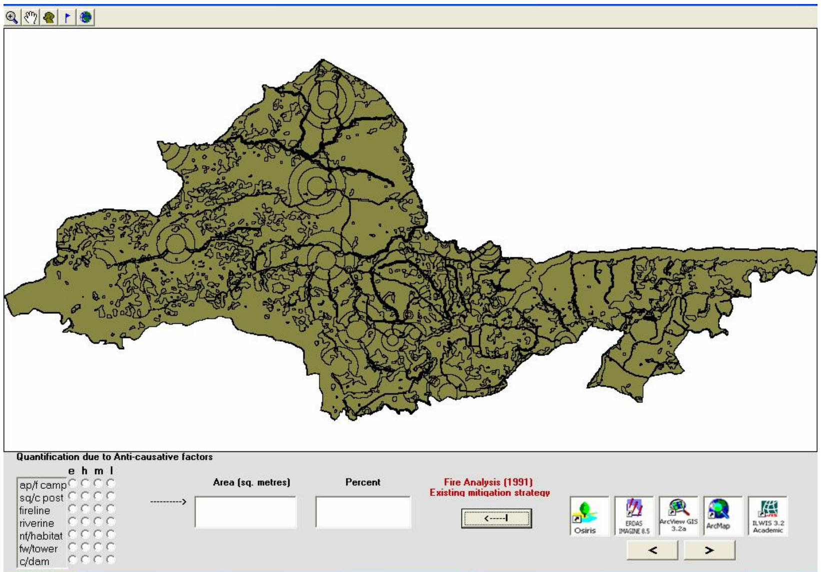


Figure 5. 53: Customization of Mitigation strategy envisaging anti-causative factors

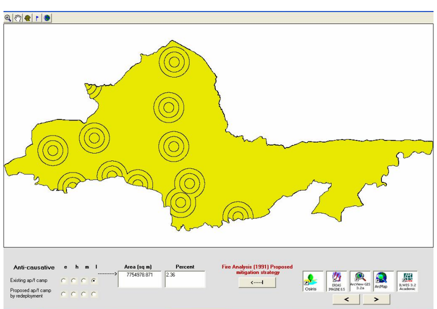


Figure 5. 54: Zone of influence of Anti-poaching/ Fire camps

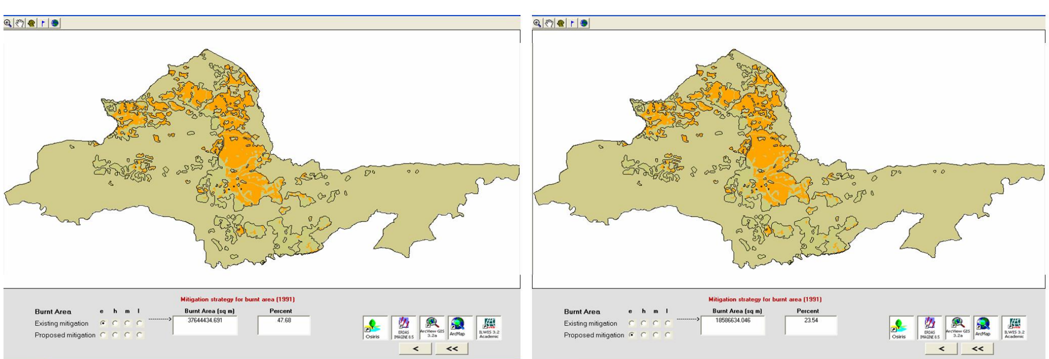


Figure 5. 55: Existing mitigation (fire 1991) & Proposed mitigation (fire 1991)

5.6.2. Menu driven tools

In Customization, map layer has been added to a Map Control through a geo-data source via the Geo Dataset object as its property. A map layer object has a Symbol object as its property to specify how the layer is displayed on a Map control. The standard control properties which have been accomplished through customization include Extent, Full Extent, Pan, Zoom-in/ out, and Refresh as under:

Full Extent - Set Map1.Extent = Map1.FullExtent
Extent - Set Map1.Extent = Map1.TrackRectangle
Min.Width - Map1.MinWidth = 2000
Zoom (two) - Set Map1.Extent = Map1.Extent.ScaleRectangle(2)
Pan - Map1.Pan

The icons for the various functions as well as detailed analysis have been placed on the customized page for easy operation.

5.6.3. Spatial and Non-spatial queries

The GIS customization has been carried out in such a way so as to retrieve the necessary spatial data as a map output and along with related attributes. The features are mainly selected by search expression with the following syntax:

Set variable = object.SearchExpression(expression)

The result of the query is a RecordSet object that contains only those records that fulfil the query condition (Annex 5.6). The prototype has been developed in such a manner, so as to account for any modifications by changing the input data and related different output.

Detailed analysis

For visualizing different scenarios and effect of changes in the parameters of the variables, the customized page offers detailed analysis through different GIS software. The access has been developed by the following syntax:

Shell (“C:\-----------\ .exe”)

The customized page offers access to the following GIS software:

OSIRIS, ILWIS Academic, ERDAS IMAGINE, ArcView and ArcMap.

We can effect necessary amends in the raw data, import through MapObjects in Visual Basic and see the changed scenario.

6. Discussion

This chapter provides the role and significance of the various causative and anti-causative factors of forest fire vis-à-vis fire burnt areas in the Protected Area conservation. It provides the importance and significance of developing the forest fire likelihood model including its implementation in the Protected Area. The chapter also details the importance of including area value in prioritizing various management interventions. It also highlights the significance of envisaging GIS approach in planning and developing mitigation strategy. Finally, the chapter provides the significance of GIS customization an easy access to the user for detailed analysis and performing various spatial and non-spatial queries.

6.1. Role of causative factors

Forests, of Mudumalai wildlife sanctuary, have been subjected to fire primarily due to the manmade reasons from January to March. From the results of overlay technique with the fire burnt areas, it is quite evident that antler collection contributes to the major causative factor for forest fire occurrence which is followed by uncontrolled tourism, poaching and grazing. There could be possible overlaps between various factors but by and large, ecological separation does exist amongst most of the factors. The common feeling that any fire is caused by the locals and villagers or for that matter by the graziers or tourists in the area doesn't sound plausible for majority of the fires. Most of the fires may be for commercial reasons (antler collection) or for easy visibility/ attracting the target species (poaching) or may be for getting fresh flush of grass (grazing) or as a case of negligence (uncontrolled tourism). The overlay of fire burnt areas (first phase data set of 1991-95) with various causative factors has helped in obtaining the pre-dominance of a particular factor in the study area. The concept of envisaging causative factors in the research becomes highly significant as the same does point towards reason and occurrence of the fires in the study area. However, the likelihood of that factor with the forest fire is also dependent on the flammability of the habitat.

6.2. Role of anti-causative factors

It is also evident from the results that anti-causative factors play an important role in retarding the chances of likelihood of fire due to various causative factors. The burnt area for 2000-2005 had been considered to assess the implications/ effectiveness of anti-causative factors, as the ban on the operation of private vehicles in the tourism zone and stationing of anti-poaching/ fire camps became significant in the second phase. The overall trend in terms of major causative factor/s remains the same but anti-causative factors do account for significant reduction. During this phase, there appears drastic reduction in the fire occurrence which could be attributed to the stationing of the anti-poaching cum fire camps in the year 2000 and ban on the operation of private vehicles as a result of controlled tourism. However, a major fire in the year 2002, resembling trend of the first phase, could be attributed to the poacher's movement as is evident from the only poaching incidence recorded in that year during the second phase. Similarly, fire in the year 2005 could be explained by the substantial rain in the previous year (rainfall data) leading to the availability of sufficient flammable dry grass and absence of any manned anti-causative factor. From the overlay of burnt areas and considering the zone of influence of various factors, it can be reiterated that the anti-poaching/ fire camp (AP/F camp) happens to be the most effective factor. Amongst the natural feature, perennial and seasonal drainage having riverine vegetation appears to be quite effective.

6.3. Significance of Likelihood model

The significance of the forest fire likelihood model lies in the fact that it envisages the need for igniting the area (causative factor), operation of anti-causative factors and flammability of the habitat. The forest type of the study area is primarily deciduous which is quite susceptible to the forest fire and forms the major (flammability) habitat. The likelihood of fire is comparable in terms of trend and influence in respect of causative factors with and without (flammability) habitat but the same is not true for the anti-causative factors, probably due to the location of management interventions. It has been observed that the antler factor contributes significantly in the likelihood of fire followed by poaching. Whereas in anti-causative factors, natural factors do have a significant role but the AP/F camp (manned structure), which happen to be the most critical factor as per its zone of influence, needs redeployment in certain places. The model accounts for various scenarios as a result pair-wise comparison and considering the values on ordinal scale in knowledge matrix keeping the critical causative and anti-causative factor vis-à-vis flammability of the habitat. For instance, in uncontrolled tourism (before1995) and controlled tourism (after 1995), it has been observed that there exists change in the scenario of the likelihood of forest fire with reduction in the extreme category. Similarly, anti-causative factors, especially anti-poaching camps became operational since 2000 and the same has bearing on the overall reduction of the forest fire. The likelihood model accounts for most of the areas burnt during 1991 and 1995 as a result of causative factors and majority of the burnt area falls in the extreme category (73-80%). Between 2000 and 2005, it has been observed that there appears overall reduction in the burnt area as a result of anti-causative factor which is also reflected in the likelihood model. The burnt area falls in both extreme and high categories with the latter accounting for more as a result of new areas (1 time) added to the cumulative set in 2004 & 2005. The model accounts for nearly 67% of the cumulative burnt area between 1991 and 2005.

As per the Likelihood model, the results indicate towards the robustness of the model. The inferential statistics envisaging linear regression and correlation with Multiple-R of 0.79877, F-value of 137.48493 and Correlation coefficient of 0.76026 is considered quite significant and suggests for positive correlation with the ground situation. Statistically, it has been observed that the antler factor has the maximum influence on the Likelihood model when compared to the other factors and with no influence of the demographic factors. The results also indicate that when the changes in the model structure have been undertaken, the change in the generic output of the model doesn't indicate any significant change. With the change in the individual variable, the change appears negligible whereas when carried out in combination, the change appears partial. The statistical analysis also indicates that the model is insensitive to moderate changes in the parameters of all variables. However, with high variation in the parameters of critical variables, the model shows partial departure from one category to the other in certain areas. The change has been observed to be within the statistical limits.

6.4. Significance of Area Value model

The importance of the area value evaluation model lies in the fact that the same is extremely significant in the planning and evaluation of various management interventions. The area value evaluation model reflects on the ecological, economic and social values. From the model, it has been observed that the different values viz. geomorphic (catchment & rocky gorge), biological (wetland & wildlife) economic (teak plantation and vegetation) and social (grazing and recreational) values account for planning of the management interventions. The result of the cross of habitat (flammability) map with the area value map provides for the total area value from the perspective of fire likelihood. It is has been observed that nearly 16% of the study area has extreme value which has been considered as significant in terms of management intervention and regular fire incidences. The results also indicate that as per the Likelihood model, there appears reduction in the extreme & high categories and related increase in the low and moderate categories when crossed with the area value. Similar results have been observed in respect of the fire burnt areas.

6.5. Significance of Mitigation Strategy model

The various mitigation strategies have been evaluated by considering the zone of influence of each management intervention. It has been observed that the anti-poaching/ fire camps act as the major deterrent in the likelihood of the fire. The location of such camps in the strategic location plays an effective role in the reduction of the extreme likelihood ness due to the presence of personnel and daily patrolling by the camp staff. It has also been observed that the riverine factor contributes significantly as a management intervention. The other manned feature (staff quarter/ check post) doesn't contribute so significantly, because of its location and other tasks assigned to the staff. The unmanned structures, especially fire lines, play a significant role in checking fire spread in the other area but have a limited role in prevention. Prioritization of the mitigation strategy by development of grid provides appropriate location of the various management interventions vis-à-vis likelihood model with area value. The prioritization at the beat (administrative unit), compartment (management unit) and grid level (location) suggests the most appropriate redeployment of the existing management interventions especially location of anti-poaching/ fire camps. The redeployment as per the proposed mitigation strategy model provides for further reduction in the extreme category of likelihood ness and related increase in the lower and moderate likelihood. The model thus provides for any deletion or addition of management intervention for effective management.

6.6. Significance of GIS Customization

The GIS customization provides for analysis of the tables associated with the data sets and running of both spatial and non-spatial queries along with detailed analysis. The customized page provides for the information on different scenarios and data access by entering into the specific theme of causative and anti-causative factors, fire likelihood, area value and existing as well as proposed mitigation strategy. It provides spatial distribution on the map as well as quantification in terms of extent of coverage (in sq. metres and percent). The customized page has also been developed for the detailed analysis through different GIS software for modified scenario. The developed prototype for analysis of fire burnt area of 1991 offers user a fair idea of the significance of causative and anti-causative factors, fire likelihood, importance of area value and effectiveness of management interventions. The search expression has been employed in GIS customization for the retrieval of the spatial data as a map output along with related attributes. Such customized outputs can be effectively utilized in concurrent evaluation of the problem and amelioration of the situation.

7. Conclusions & Recommendations

This chapter concludes with the findings on various research sub-objectives vis-à-vis results and details the various recommendations. Besides, recommendations for the study area, the chapter also provides future research potential.

7.1. General Conclusions

Fire prevention and detection is one of the most important management considerations in most of the Protected Areas (PA). Many wildlife areas have achieved a great degree of success in protecting their areas from fire or in extinguishing fires efficiently whenever detected. Efficient fire protection requires adequate logistics, infrastructure and funding for prevention and suppression of fire. But for developing efficient fire management plan, it is important to have a detailed knowledge on the fire risk areas. The probability of forest fire can easily be analysed and managed through GIS and remote sensing. Innumerable forest fire model exists which help in taking decision towards effective fire management using spatio-temporal database system.

The study makes it possible to have the realistic assessment of the likelihood of forest fire in a scientific manner. It allows prioritizing of the fire risk areas as per the causative and anti-causative factors with consideration of area value. The model helps in evaluating and planning appropriate mitigation measures. Such a ground-based model can provide a realistic assessment of the field situation with a site specific fire management plan.

7.2. Addressing research objectives vis-à-vis results

7.2.1. To identify the possible causative factors for forest fire occurrence

What are the possible causative factors for forest fire occurrence?

From the literature review, the possible causative factors of the forest fire occurrence were categorized into two main classes viz. natural and man-made. The natural causes of forest fires were attributed primarily to the lightning strike and sometimes as a result of rockfall or by friction between bamboo culms. Man-made reasons were mainly attributed to intentional and accidental reasons. The intentional causes were broadly grouped into forest exploitation (lumbering, grazing and non-timber forest produce collection), debris burning (clearing) and incendiary reasons. Accidental reasons were mainly due to the railroads & railways (sparks from train, maintenance works and negligence by passer-by), tourist activities (cooking, smoking, camping and pilgrimage) and miscellaneous (escape of fire in controlled burning, during pine resin tapping, crashing of aircraft etc)

How to identify the major causative factors responsible for forest fire occurrence?

The causative factors for forest fire occurrence in the study area were short-listed by the perusal of the management plan, fire reports and relevant articles specific to the Protected Area. The factors identified were antler collection, poaching (mainly for ivory), uncontrolled tourism, livestock grazing, enclaves &

settlements, adjoining estates and peripheral villages. The zone of influence of the major causative factors was identified with the habitat (flammability) map.

How to identify forest fire occurrence as a result of that particular factor?

The major causative factors were identified by the help of classification, digitization and overlay of the burnt areas with the respective causative factors map. The overlay of fire burnt areas with various causative factors provided the pre-dominance of the particular causative factor in the specific area. The antler collection contributed to the major causative factor for forest fire occurrence followed by poaching and uncontrolled tourism. The other factors viz. grazing, pressure from enclave, estate and village had their own zone of influence.

How to identify the anti-causative factors (agents)?

Like causative factors, the anti-causative factors in respect of the study area were also grouped as natural and man made factors. The natural factors were identified as riverine and non-flammable forest patches including rocky outcrops whereas man-made factors included manned and unmanned structures and features. Manned structures included anti-poaching/ fire camps and staff quarters/ check posts whereas unmanned structures and features included fire lines, fire watch towers and check dams. Besides, controlled tourism zone was also identified as an anti-causative factor. The zone of influence of each anti-causative factor was calculated and the same was overlaid with the burnt area of the second phase to establish the prioritization of various factors. Anti-poaching/ fire camps were quite effective in the reduction of the overall burnt area.

7.2.2. To evaluate forest fire likelihood by developing a fire likelihood model

What are the data requirements for developing the forest fire likelihood model?

The forest fire likelihood model had been developed on GEOPS framework which envisaged a wide range of knowledge models. The basic concepts in the GEOPS domain model included a system and a set of subsystems with one or more attributes in OSIRIS. The source included use of data in ESRI Grid and knowledge matrix. The case dependency had been developed with the set of connections between system attributes and sources. The contents of the case had been described by these connections through different scenarios. The various maps related to the causative factors, anti-causative factors and habitat flammability were included in the system attributes. A base cross map was used to generate the different pair-wise comparison maps pertaining to causative and anti-causative factors as a result of use of knowledge matrix. The animal distribution dependent factors (antler collection and poaching) accounted for the maximum fire as per the model. This was followed by the management related factors (tourism and grazing) and demographic related factors (estates, enclaves and villages) were not very significant. In OSIRIS, different scenarios had been generated by assigning different weightings to the causative factors vis-à-vis habitat. Similarly, different scenarios were also generated for the anti-causative factors including natural and man-made structures and features. As per the model, anti-poaching/ fire camps acted as the major deterrent in the likelihood of the fire and overall reduction of incidences.

How to realistically assess the likelihood of forest fire from the model?

The time series data used in the model from 1991-95 and 2000-05 helped in the realistic assessment of the likelihood ness of the fire. Different scenarios from the model were generated to explain for the influence of various causative as well as anti-causative factors vis-à-vis burnt areas of various years. For instance, with the controlled tourism model exhibited reduction in the extreme category. Similar, overall reduction was seen by the deployment of anti-poaching camps since 2000. From the cumulative data set, it was seen that the model accounted for all burnt areas (67%) between 1991-95 and 2000-05 in the priority categories i.e. 75-80% in the extreme and high categories of likelihood. The Likelihood model so developed had been tested statistically for sensitivity analysis. The results indicated towards the robustness of the model. The inferential statistics envisaging linear regression and correlation suggested towards positive correlation with the ground situation. It had been observed that the antler factor had the maximum influence on the Likelihood model when compared to the other factors. The results also indicated that the generic output of the model did not exhibit any significant change with the partial distortion and change of the model structure.

7.2.3. To establish an Evaluation model for area value & mitigation strategy

How additional factors can be incorporated for developing an evaluation model for area value and mitigation strategy?

Area Value model had been generated to establish the ecological, economic and social values in the study area. The qualitative model had been developed in the OSIRIS which envisaged the model framework GEOPS, as in the development of the likelihood model. The model incorporated different values viz. geomorphic (catchment & rocky gorge), biological (wetland & wildlife) economic (teak plantation and vegetation) and social (grazing and recreational) values which was felt critical in the planning of the management interventions. The output from the model indicated that nearly 16% of the study area had extreme value which was significant from the perspective of management intervention and regular fire incidences.

Mitigation strategy model had been developed as per GEOPS framework considering the forest fire likelihood, area value and various management interventions. In respect of mitigation strategy, only manned and unmanned management features had been considered excluding natural features. The various mitigation strategies had been evaluated by considering the zone of influence of each management intervention. It had been observed that the anti-poaching/ fire camps acted as the major deterrent in the likelihood of the fire. Prioritization of the mitigation strategy had been done by the development of grid which provided appropriate location of the various management interventions vis-à-vis likelihood model with area value. The model thus provided for any deletion or addition of management intervention for effective management.

7.2.4. To develop customization tool for visualization of fire mitigation strategy

How to visualize the outcome based on spatial and non-spatial query through interactive GIS customized tools and menus?

Customization had been carried out through a typical graphical, menu driven, icon-based graphical user interface (GUI) which envisaged use of geo-processing tools. At the GUI level, it involved configuring the form and appearance of the interface whereas, at the tools level, customization involved creating of macros to automate frequently required processes and adding of new functionalities. A simple prototype had been developed in the Visual Basic environment using ESRI Map Object 2.1 for the GIS customization. Maps generated as a result of Likelihood, Area value and Mitigation strategy models including base maps of causative and anti-causative factors were taken as inputs in the Map Object library. Attribute table having spatial and non-spatial data were also utilized for running both spatial as well as non-spatial query. The customization also provided for advanced analysis using GIS software viz. OSIRIS, ERDAS IMAGINE 8.6, Arc View 3.2, Arc Map 9.0 and ILWIS 3.2. The GIS customization provided for the analysis of the tables associated with the data sets and running of both spatial and non-spatial queries along with detailed analysis. The search expression had been employed in GIS customization for the retrieval of the spatial data as a map output along with related attributes. The developed prototype for analysis of fire burnt area offered user a fair idea of the significance of causative and anti-causative factors, fire likelihood, area value and effectiveness of management interventions.

7.3. Recommendations

The recommendations from this study can be implemented for the study area as well as for the areas with similar type of field situations with site-specific adjustments. Also, future potential can be suggested for further research.

7.3.1. Recommendations for Study area

The following recommendations are suggested for the study area:

- The influence of antler collection as causative factor for fire appears to be very significant; hence, monitoring and distribution pattern of the deer population is suggested in the flammable habitat to have a better control to avert fire incidences.
- The poaching hotspots as per the likelihood model needs to be further strengthened by increased patrolling in the area during fire season.
- Practice of controlled tourism and ban imposed on the operation of private vehicles in the tourism zone needs to be continued.
- Grazing control and restriction can be exercised during the fire season in the areas open for grazing.
- Location of anti-poaching/ fire camps need to be redeployed as per the mitigation strategy model with new locations as per the suggested model for better fire management and control.
- Fire line network to be prioritized as per the area value model for restricting fire damage.
- Critical fire watch towers can be identified as per the likelihood model and manned in the fire season to increase the zone of influence of anti-causative factor for fire prevention.

7.3.2. Recommendations for further research

Future potential for further research is suggested as under:

- To develop a more robust model incorporating various topographic (slope, aspect and elevation) and environmental (wind velocity, relative humidity and rainfall) variables including crown fire.
- How fire likelihood model can account for fire spread model vis-à-vis remote sensing parameters.
- To employ other methods like decision tree for evaluating variables in the model and compare the same with the knowledge matrix.
- To develop linkages with the other environmental models dealing with the issues of air pollution, soil - moisture conservation and microclimate preservation.
- To extend the scope of the model from local level to state, national, regional and global levels by incorporating essential adjustments and parameters.

7.4. Final Remarks

Protected Areas (PA) that are confronted with potentially destructive fires develop fire management plans in such a way so as to modify fire’s impact on people, value of the area and ecosystem processes. The plans objective is determined by the ecological, economic, social and political considerations. The extent to which any plan achieves its objective depends upon the following:

- how well the fire and ecosystem processes and the impact of fire management are understood
- the degree to which the social and economic impacts are perceived
- the technology and resources available at the disposal of the planner
- the knowledge, skills and experience of the field staff

- the challenges posed by the environmental variables

The development and implementation of the fire model based on the causative and anti-causative factors is relatively simple and straight forward when compared to the other challenges faced by the park managers. It is therefore imperative on the part of the park manager to decide upon the appropriate utilization of the fire fighting resources, predict fire occurrence, deploy resources in the areas of fire likelihood and deal efficiently with any fire. But such challenges are manageable when we understand the various ecological and socio-economic impacts as a result of human intervention and wildlife conflict in the area and implementation of the site-specific fire management strategy.

Glossary

Causative factor - refers to those factors, as a result of which, area is getting burnt regularly

Conservation measures - refers to the management interventions taken as a part of mitigation

Fire Risk - is the probability of harmful consequences or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable/ capable conditions
(Risk is conventionally expressed by the equation: Risk = Hazard x Vulnerability)

Fire Hazard - is a potentially damaging physical event, phenomenon and/ or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation

Fire Vulnerability - is a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of a community to the impact of hazards

Fire Severity - refers to the magnitude of significant negative impact on wildland systems

Fire Likelihood - refers to the chance of area getting burnt as a result of a particular causative factor

Fire Occurrence - refers to an active fire that happens when the fire begins to spread through the forest fuel complex as a surface fire or a crown fire and emits significant amounts of smoke and energy.

Fire Ignition - refers to the fire occurrence. (includes potential fire ignition or fire source)

Fire Frequency - is the number of fires per unit time in a specific area

Fire Interval - is the elapsed time between two successive fires in a specific place

Fire Cycle - is the number of years necessary for an area equal to the entire area of interest to burn

Fire Rotation - is also known as fire cycle

Protected Area - area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, natural and associated cultural resources, managed through legal or other means

Visualization - refers to the easy visual perception of the information using GIS customization

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Appendices

Annexure 5.1: Density details of the Deer population for Antler distribution computation

Density of Ungulates (Deer) species						
Range	**Beat**	**Comp.No**	**2005**	**2004**	**2002**	**Avg.**
Nellakottai	Benne	29	0.00	53.40	36.07	29.82
		30	-	51.51	-	51.51
		31	-	46.71	-	46.71
	Mukkatti	32	0.00	-	-	0.00
		33	0.00	-	2.32	1.16
		34	0.00	-		0.00
	Nellakottai	35	-	23.79	10.59	17.19
		36	-	7.25	10.59	8.92
		37	-	-	-	0.00
		38	0.00	34.99	20.75	18.58
		39	0.00	50.69		25.35
Mudumalai	Jaldari	jal	76.25	22.32	9.62	36.06
	Bospara	20	0.00	-	-	0.00
		21	-	27.46	2.87	15.17
		22	-	-	-	0.00
	Mudumalai	23	-	25.61	7.21	16.43
		24	-	25.93	26.72	26.33
		25	0.00	39.13	26.72	21.95
		26	12.50	27.46	17.67	19.21
		28	76.25	18.50	17.67	37.47
Theppakadu	Doddagatti	dod	29.38	16.10	5.02	16.83
	Imberallah	imb	33.75	14.79	2.40	16.98
	Kakanallah	27	107.50	34.97	-	74.24
		15	107.50	40.41	-	73.96
		7	-	14.52	-	14.52
		8	0.00	-	-	0.00
	Theppakadu	9	-	-	-	0.00
		10	-	34.04	1.78	17.91
		16	78.75	42.97	-	60.86
Kargudi	Nellikarai	18	112.50	-	-	112.50
		19	112.50	41.10	-	76.80
		6	-	10.76	-	10.76
	Thorapalli	3	65.00	-	17.61	41.31
		4	-	7.39	17.61	12.50
		5	65.00	-	-	65.00
	Kargudi	17	78.75	38.95	-	58.85
		1	78.75	-	-	78.75
		2	65.00	65.70	17.61	49.44
		11	-	2.18	-	2.18
Masinagudi	Morganbetta	13	15.00	0.00	11.06	8.69
		14	15.00	-	-	15.00
	Masinagudi	12	25.00	-	17.86	28.12
	Mavinhalla	12	26.25	41.51	0.86	13.56
	Avarhalla	12	8.75	-	2.41	20.95
	Moyar	12	18.75	-	-	48.74

(Source: Census details of Forest department, Tamilnadu)

Annexure 5.2: Elephant Poaching incidences from 1992 – 2005

Poaching details for Elephants				
Year	**Range**	**Beat**	**Comp. No**	**Nos**
1992	Nellakottai	Benne	30	1
1993	Mudumalai	Mudumalai	24	2
	Masinagudi	Masinagudi	12	1
1994	Theppakadu	Doddagatti	Dod	1
1995	Masinagudi	Morganbetta	14	1
	Nellakottai	Benne	30	1
	Theppakadu	Kakanallah	15	1
1996	Theppakadu	Kakanallah	7	1
1997	Mudumalai	Mudumalai	24	2
	Kargudi	Nellikarai	6	1
1998	Mudumalai	Jaldari	Jal	1
	Theppakadu	Kakanallah	27	1
	Theppakadu	Kakanallah	8	1
	Kargudi	Nellikarai	6	1
	Masinagudi	Morganbetta	13	1
1999	-	-	-	0
2000	-	-	-	0
2001	-	-	-	0
2002	Theppakadu	Doddagatti	Dod	1
2003	-	-	-	0
2004	-	-	-	0
2005	-	-	-	0

(Source: Offence details of Forest department, Tamilnadu)

Annexure 5.3: Teak Plantation Area

Teak Plantations (in ha)			
Range	**Beat**	**Comp.No**	**Area**
Nellakottai	Benne	29	6.07
		30	6.07
	Mukkatti	32	6.37
		33	36.31
		34	19.76
	Nellakottai	35	15.38
Mudumalai	Bospara	20	13.35
Theppakadu	Kakanallah	8	8.09
	Theppakadu	9	6.88
		10	2.02
Kargudi	Nellikarai	18	23.88
		19	34.58
		6	58.28
	Thorapalli	3	101.85
		4	56.19
		5	209.12
	Kargudi	1	117.72
		2	51.20
Masinagudi	Morganbetta	13	2.02
		14	10.12

(Source: Management Plan of Mudumalai Wildlife Sanctuary)

Annex 5.4: Density of Important Plant species from wildlife perspective

Density of Important plant species in wildlife habitat			
Species	**Thorn/ Scrub**	**Dry deciduous**	**Moist deciduous**
Acacia catechu	27.68	0.28	0.00
Anogeissus latifolia	33.21	79.71	11.00
Cassia fistula	1.61	1.27	7.00
Eriolaena quinquilocularis	0.00	14.58	2.75
Grewia tillaefolia	0.36	3.31	19.75
Kydia calycina	0.00	0.00	254.00
Lagerstroemia sp.	0.00	11.97	24.25
Phyllanthus emblica	1.43	5.28	6.25
Tectona grandis	0.71	102.25	19.25
Terminalia sp.	0.00	27.26	37.25
Zizyphus sp.	15.17	8.73	0.00

(Source: Indian Institute of Science (IISC) Report in the Management Plan)

Annex 5.5: Total Importance Value of Vegetation types

Total Importance Value (TIV) of Forest	
Vegetation type	**TIV**
Evergreen	6.16
Semi-Evergreen	6.43
Moist deciduous	10.43
Dry deciduous	9.81

(Source: Indian Institute of Remote Sensing (IIRS) Report)

Annex 5.6: Coding for Search Expression

```
Private Sub Option_Click()
Dim myRecst As MapObjects2.Recordset
Dim myLayer As MapObjects2.MapLayer
Set myLayer = Map1.Layers("….")
Dim exp As String
exp = "….=…. ORDER BY …."
Set myRecst = Map1.Layers("….").SearchExpression(exp)
Dim myPoly As MapObjects2.Polygon
myRecst.MoveFirst
Do While Not myRecst.EOF
Set myPoly = myRecst.Fields("SHAPE").Value
Map1.FlashShape myPoly, 2
Text.Text = myRecst.Fields("AREA").Value
Text.Text = myRecst.Fields("PERCENT").Value
myRecst.MoveNext
Loop
End Sub
```