# Forest fire risk modelling using remote sensing and geographic information system

Abhineet Jain, Shirish A. Ravan, R. K. Singh*, K. K. Das, P. S. Roy

Indian Institute of Remote Sensing, 4, Kalidas Road, P. B. No. 135, Dehradun 248 001, India

*Madhya Pradesh Remote Sensing Application Centre, Bhopal 462 011, India

**We present here an integrated remote sensing and Geographic Information System (GIS) approach for prioritization of the forest fire risk areas in a part of Rajaji National Park (Uttar Pradesh), India, which lies in the fragile ecosystem Siwalik Himalayas. The important factors favouring the forest fire and its spread, viz. fuel content in the forest, proximity to roads/fireline and settlement and the topography were integrated to obtain a fire risk zone map of the study area. Integration of different informations was made possible through PAMAP GIS. Almost 50% of the study area was predicted to be under very high and high risk zones, mainly concentrated in the fringes of the park. A comparison between predicted risk area and actual burnt areas during 1985–93 showed that 41.49% of the previously burnt area fell in the high and moderately high risk zones, suggesting that the approach was useful as a predictive tool.**

FOREST is a major natural resource and plays an important role in maintaining environmental balance. After deforestation, forest fire is the next most important cause which does incalculable harm to the extensive forest area. The burning associated with such conversion leads to higher concentrations of various greenhouse gases, larger aerosol concentration and smoke-like layer over the burning areas, increased surface albedo and a decrease in evapotranspiration[1]. Burning forest and woodland probably account for roughly one quarter of all carbon dioxide build up, besides damage to the timber and its value[2].

Anticipation of factors influencing fire occurrence and its dynamic behaviour is a critical aspect of fire management. An imperative need is felt to prioritize such fire-prone areas which will help in ascertaining the fire suppression measures in protected areas.

The prioritization of fire risk zones is a practical concept and an aid to fire management and planning. Fire risk zones are points where there is a likelihood of fire to start and the possibility of spread of fire to other areas after the initiation of fire. The concept of 'degree of fire risk' involves measurement of all those factors which affect the ignition and behaviour of fire at a specific time.

From an organizational point of view, it is important that correct information of potential danger in parts of a protected area be available. Therefore knowledge of the factors which cater to fire environment and influence the fire behavior and its dynamics is essential. It will be of extreme interest to mark these starting points on a map, in order to recognize the logical reasons for concentration of these points in certain areas. A precise evaluation of fire problems and decisions on methods of solution can only be satisfactorily made when standardized statistical records are available.

Remote sensing has opened up opportunities for qualitative as well as quantitative analyses of forests and other ecosystems at all geographical and spatial scales. Sensors are now collecting data with broad to fine spectral resolution and with various radiometric characteristics. Satellite remote sensing data have been used since 1972 to derive land cover information. In addition to cover type mapping and inventory, remote sensing has also been effectively used in the study, monitoring and detection of forest fire[3–5]. Most of the remote sensing techniques have been based on the thermal infrared channel (3.55–3.93 μm) and the vegetation indices in order to locate areas with high risk of forest fire. Miller and Johnston[3] have tested the utility of Advanced Very High Resolution Radiometer (AVHRR) data to indicate critical fire risk period. A GIS is an important tool for storage, analysis and display of geo-referenced spatial and non-spatial data, which makes the integration of myriad variables possible, in a meaningful and efficient way. Categorical data have been incorporated into GIS with other physical, socioeconomic and institutional information to conduct spatial interaction and overlays, data aggregation and estimation and spatial modelling for many forest problems. This study was aimed at investigating a reliable model for fire risk area mapping in a part of India, focussing mainly on integration of remote sensing data with other relevant ancillary information in GIS.

The Dhaulkhand range of the proposed Rajaji National Park located in the state of Uttar Pradesh, India has been taken as the study area. The area lies within longitude 77°55'35"–78°04'42"E and latitude 29°59'45"–30°08'48" N, covering an approximate area of 150 $km^2$ (Figure 1).

Topography of the area is variable with altitude varying from 320 m above MSL in submontane area to 800 m above in Siwalik ranges. In the submontane area, the ground is apparently level but slopes gently towards south-west. The soil resulting from Siwalik sandstone is sandy loam with large proportion of clay. In higher regions of steep slopes, the soil is very shallow and dry, supporting xerophytic vegetation.

Climate of the area is subtropical. The rainy season commences in late June and continues up to the middle of September with the heaviest rainfall recorded in August (range 1200–1500 m). The temperature in the area varies from 13.1°C in January to 40°C in May and June[6].

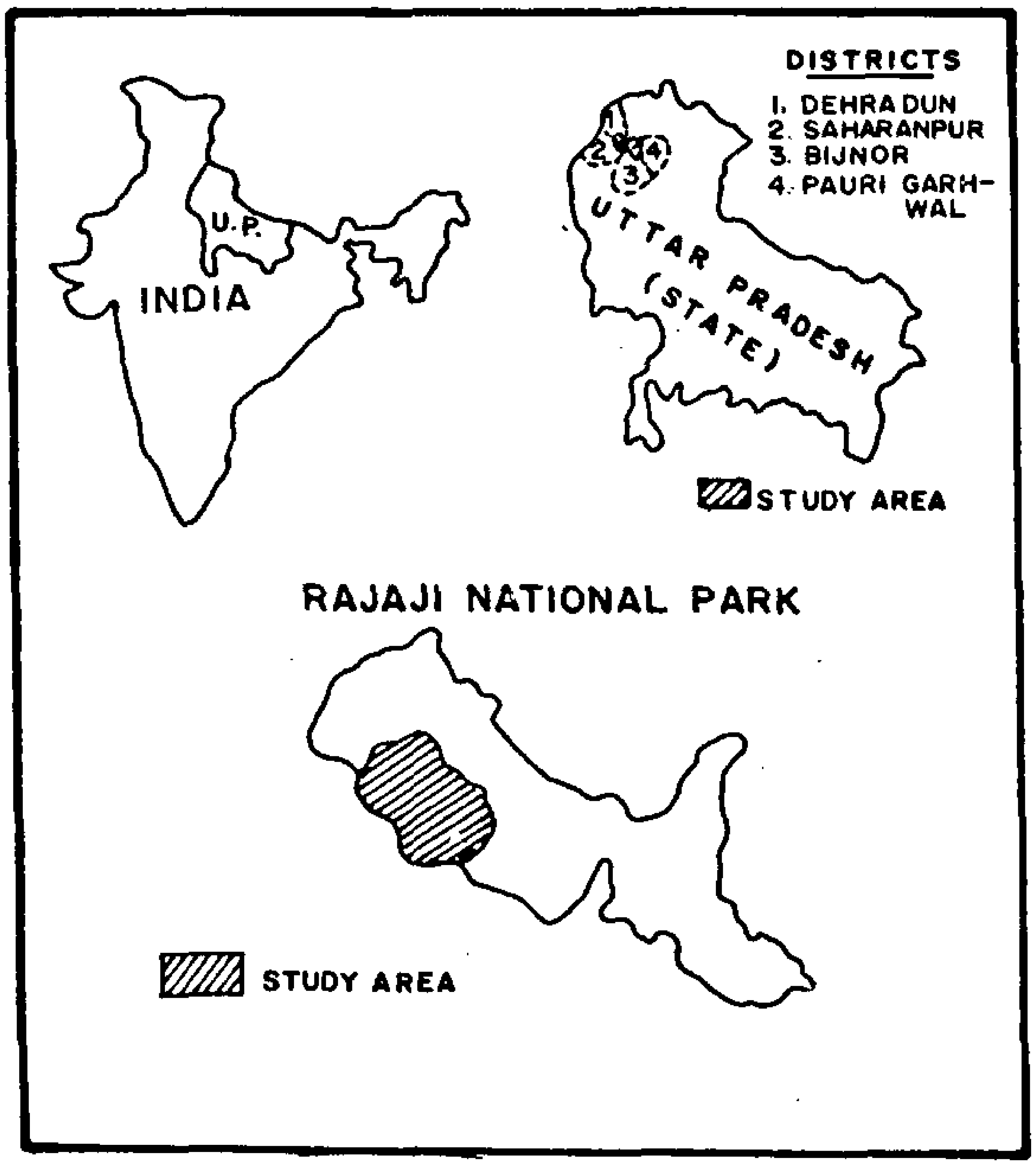


Figure 1. Location map of the study area.

Table 1. Organization of the variables in the two-level approach employed for fire risk mapping

| Source | Primary features | Secondary features |
|---|---|---|
| IRS IB (LISS II) | Vegetation type map | Fuel-oriented map |
| SOI toposheet | Elevation data | Slope map |
| SOI toposheet and ground verification | Settlement location points | Zones around location points |
| SOI toposheet | Roads/fireline network | Zones around these features |
| Landsat TM, 1986 | Fire history | Previous fire incidences and their areal extent |

Vegetation of the area mainly belongs to Northern tropical dry deciduous forest and sub-tropical forest[7]. Among the tropical dry deciduous forests, main types are dry Siwalik Sal (*Shorea robusta*) forest, while sub-tropical forest consists mainly of Chir-pine (*Pinus roxburghii*) forest. Sal forest occurs on the higher slopes of Siwalik as well as on the 'bhabar' belt. The main associates are *Termenalia tomentosa, Anogeissus latifolia, Buchnania lanzen, Termenalia belerica*, etc. The other common species in the overstorey are *Bombax ceiba, Acacia catachu, Cassia fistula, Aegle marmelos, Lagerstroemia parviflora*. The undergrowth consists of *Murraya koenigii, Adhatoda vasica, Cassia tora, Lantana camara*, etc.

In India, most of the forest fire incidences are anthropogenic in origin, because of the close proximity of the human settlements and an almost free accessibility to the forest. The peculiar and interesting feature of this national park is the residence of nomadic inhabitants inside the forest. This feature makes the study area prone to the fire hazard.

An integrated analysis approach of spatial variables was felt valuable for forest fire research[8,9]. The use of GIS has made it possible to combine several variables in order to prioritize the fire-prone areas. The integration of the information obtained from remote sensing and other sources into a geo-information system (GIS) has been done to check the feasibility of the fire risk model and to map the areas prone to fire risk.

A multi source of data set was used in the present study. The information about the vegetation types of the study area has been derived from the LISS II (Linear Image Self Scanning) data of the Indian Remote Sensing Satellite IRS IB. Other corollary data used were Survey of India (SOI) topographical maps of the study area on 1:50,000 scale, ground data collected during field visits (March 1993) and range map. Data on past fire in the study area was derived from Landsat TM (Thematic mapper) May, 1985 and from forest department reports. The different pieces of information were digitized as independent layers in PAMAP GIS (Table 1). PAMAP is a commercial PC-based Canadian GIS package available on DOS and Windows.

The forest type map of the study area was prepared by visual interpretation of IRS LISS II data based on standard image interpretation technique. The interpreted results were further verified and supported by ground data collected during field work. The thematic details were transferred on to a base map prepared from SOI topographic map (Figure 2).

A stratified random sampling approach was followed in order to estimate the fuel content value in different, homogeneous vegetation strata ascertained through interpretation of satellite data. In each homogeneous vegetation stratum 10 m × 10 m sample plots were laid for the purpose of studying the community structure (species composition and density), and 1 m × 1 m quadrats were laid to quantify the surface fuel. Litter (leaf, twig and branch) and herbaceous grasses were collected and separated out. The fuel content (fuel load) per unit area (kg/m$^2$) in each stratum was estimated after oven drying the collected samples. The presence of middle level fuel consisting of herbs/shrubs larger than 2 m length was also noted down in each plot. Fuel load was considered as the criterion for deciding the ratings of different vegetation classes[10].

The fire behaviour is largely controlled by topography. Slope is one of the factors influencing fire behaviour. The impacts of elevation, aspect and slope in fire behaviour have been widely reported in the literature[11,12]. The digital elevation model (DEM) was obtained by the weighted average interpolation of the

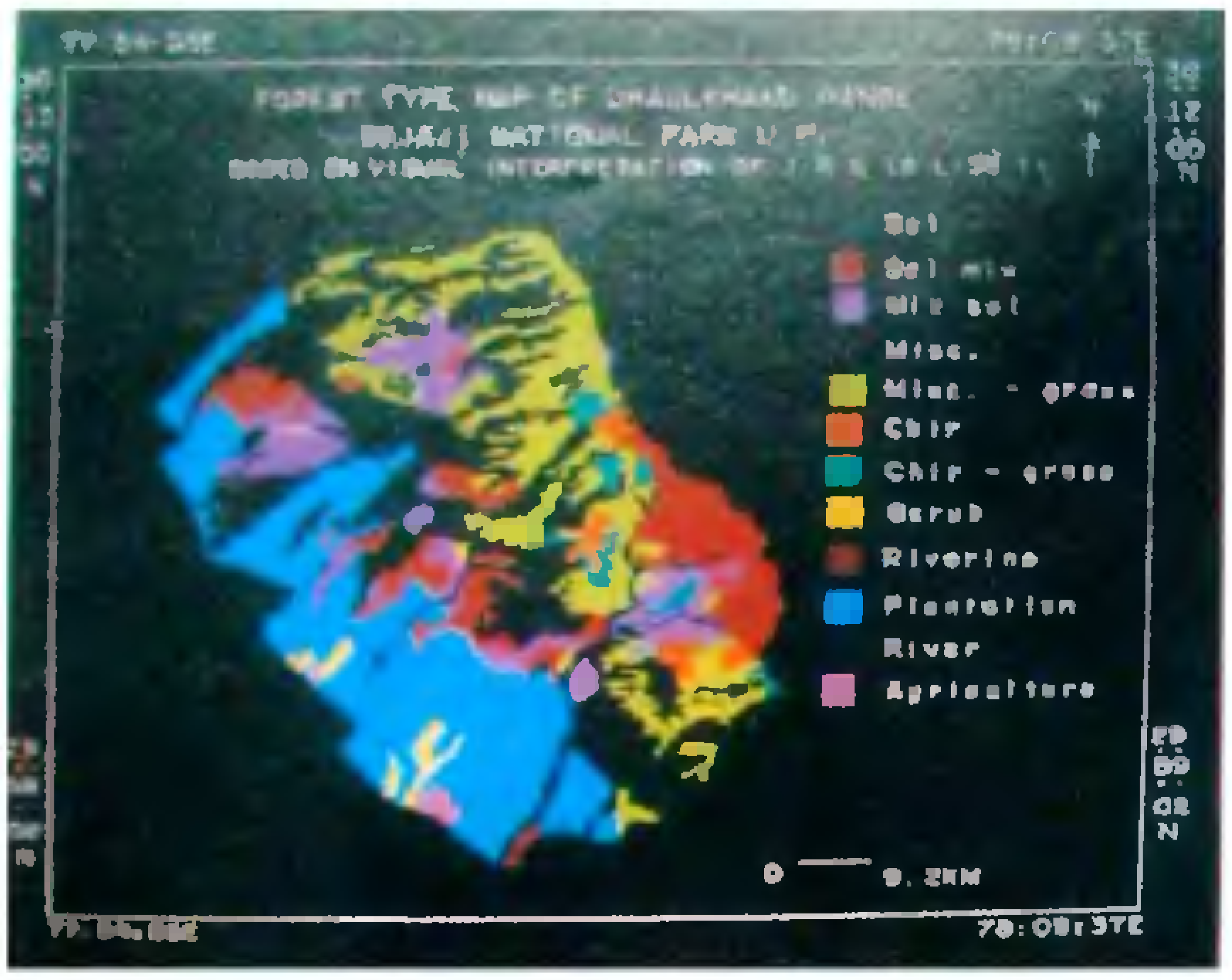


Figure 2. Forest type map of the study area.

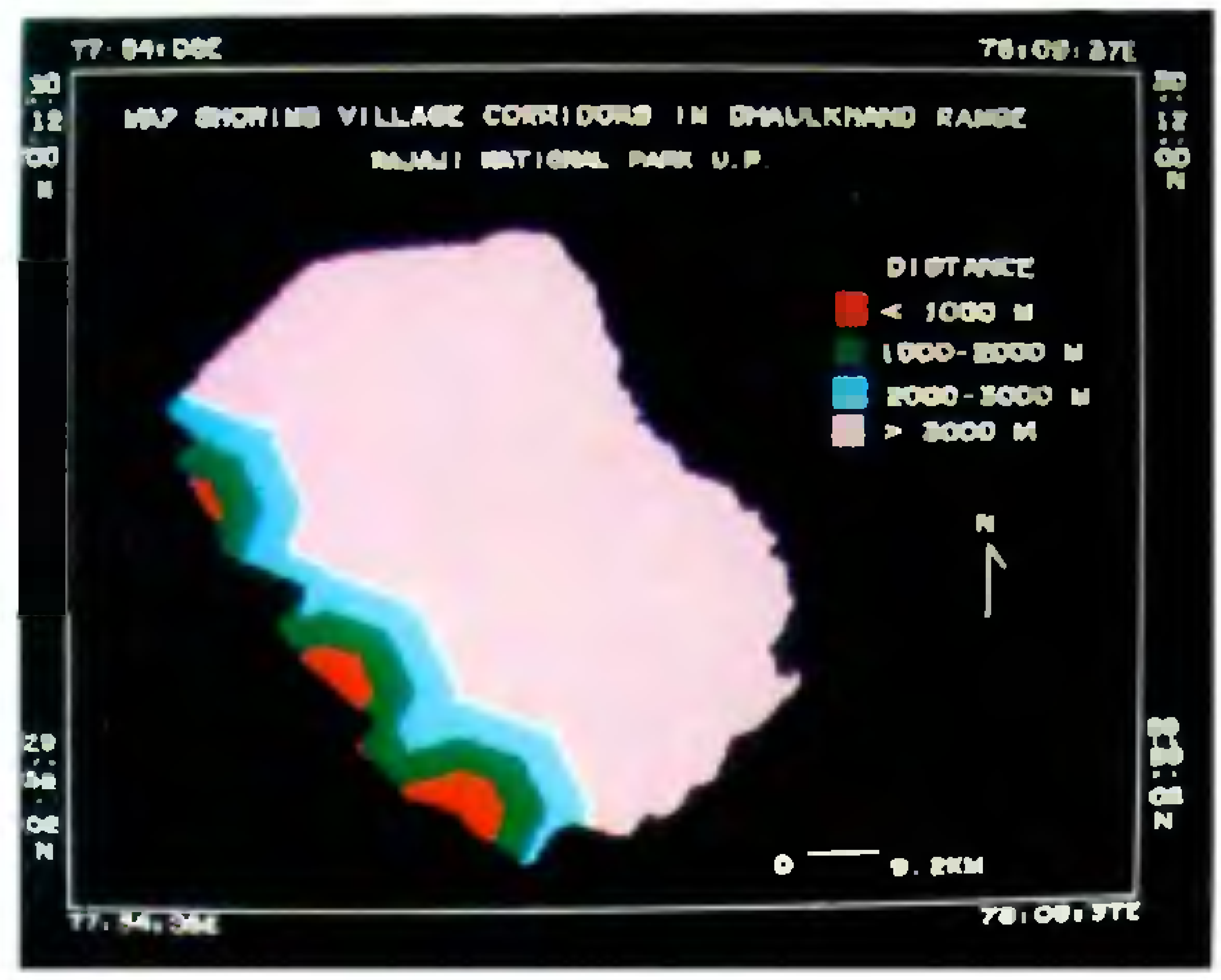


Figure 4. Map showing zones around settlement location points.

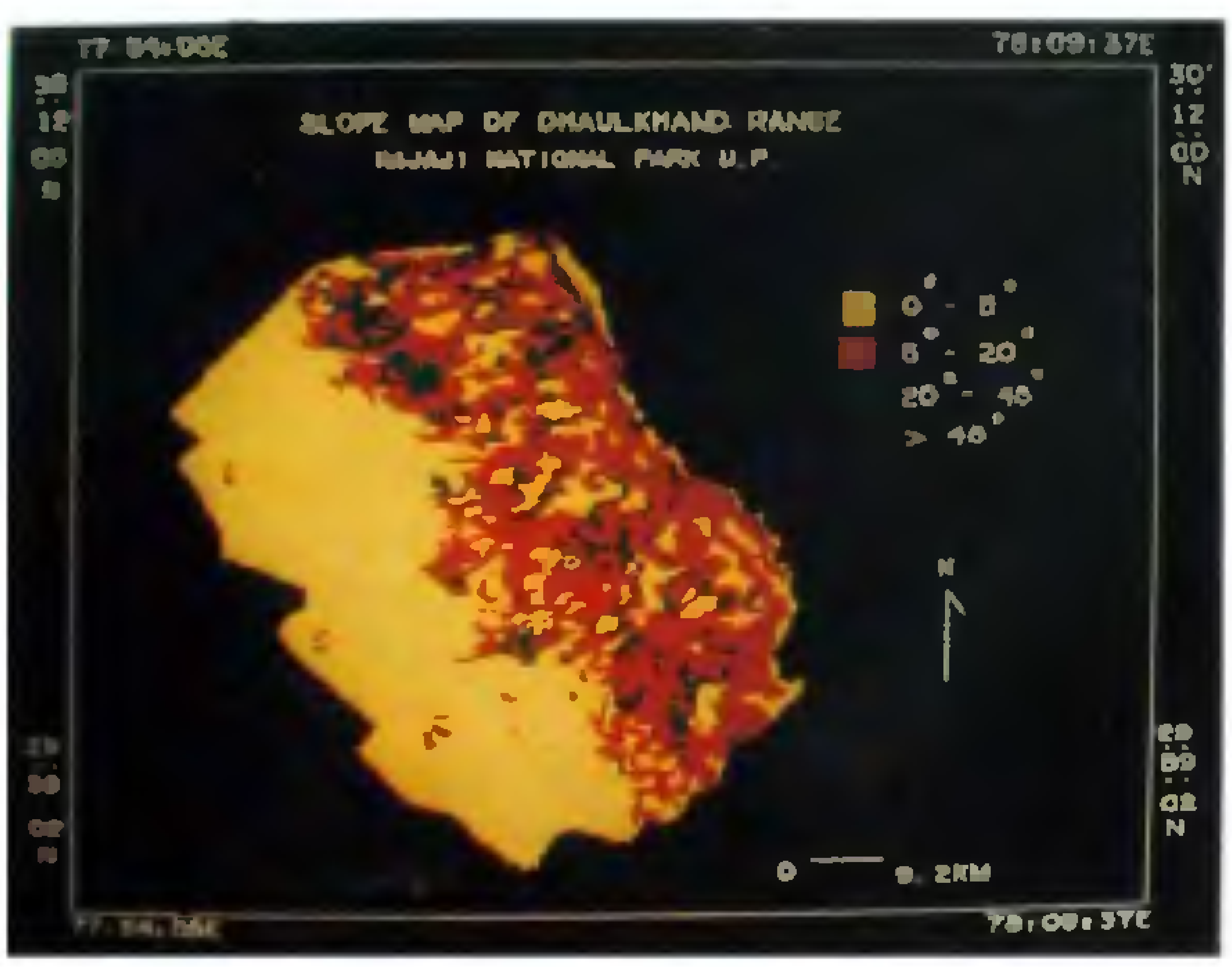


Figure 3. Slope map of the study area.

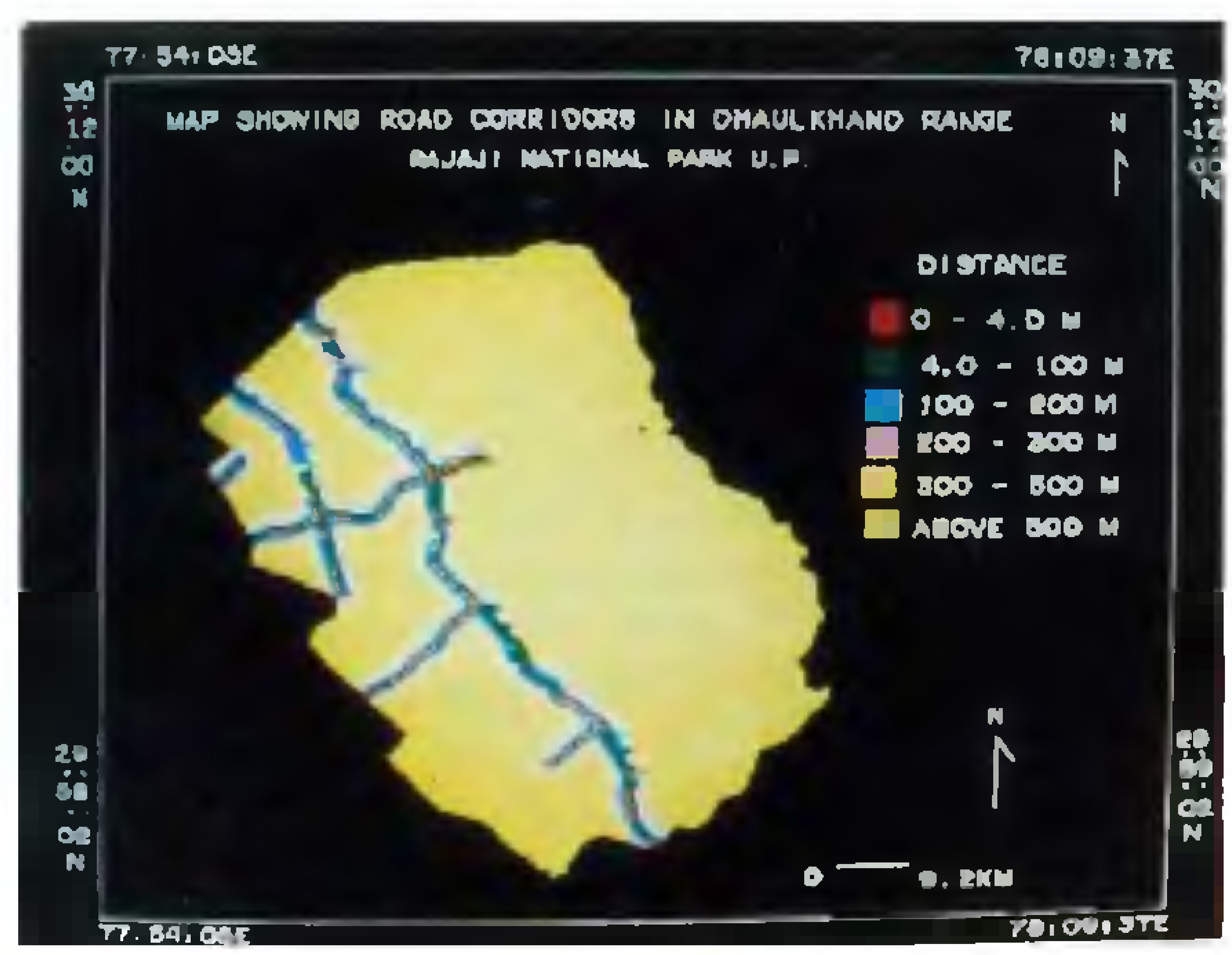


Figure 5. Map showing road/fireline zones.

digitized contour lines with an interval of 40 m in the hilly region and 20 m in the flat lands. The elevation data were taken from the 1:50,000 topographic maps. The slope was then computed from the digital elevation data and was graduated into four classes, viz. 0°–5°, 5°–20°, 20°–45° and >45°, representing gentle, moderate, steep and very steep slopes respectively (Figure 3).

The main causes for the forest fires are the human activities inside the forest area. The sources for the fire initiation could be human settlements inside or near the forest, roads/footpaths inside forest, work places of labour. The distance analysis utility of PAMAP GIS has been used to create zones around such features. The corridors of 1000 m perimeter were created around the settlement location points/residential land use, digitized as point data. The fire risk decreases with the distance (by 1000 m increment) from the location points (Figure 4).

Roads/fire lines act as barriers to the spread of fire and in that sense they are a reducing factor to fire risk, but since they are also potential routes for hiking and camping areas, they increase the fire risk because of the more intense human activity. The road/fireline network was digitized and the distance analysis utility of the PAMAP GIS has been utilized to create zones of 100 m distance intervals, along above features (Figure 5).

In the present study, integration of various influencing factors has been applied by means of a hierarchical system (Figure 6). Two levels were identified in this hierarchical system (Table 1). Influence of variables on fire

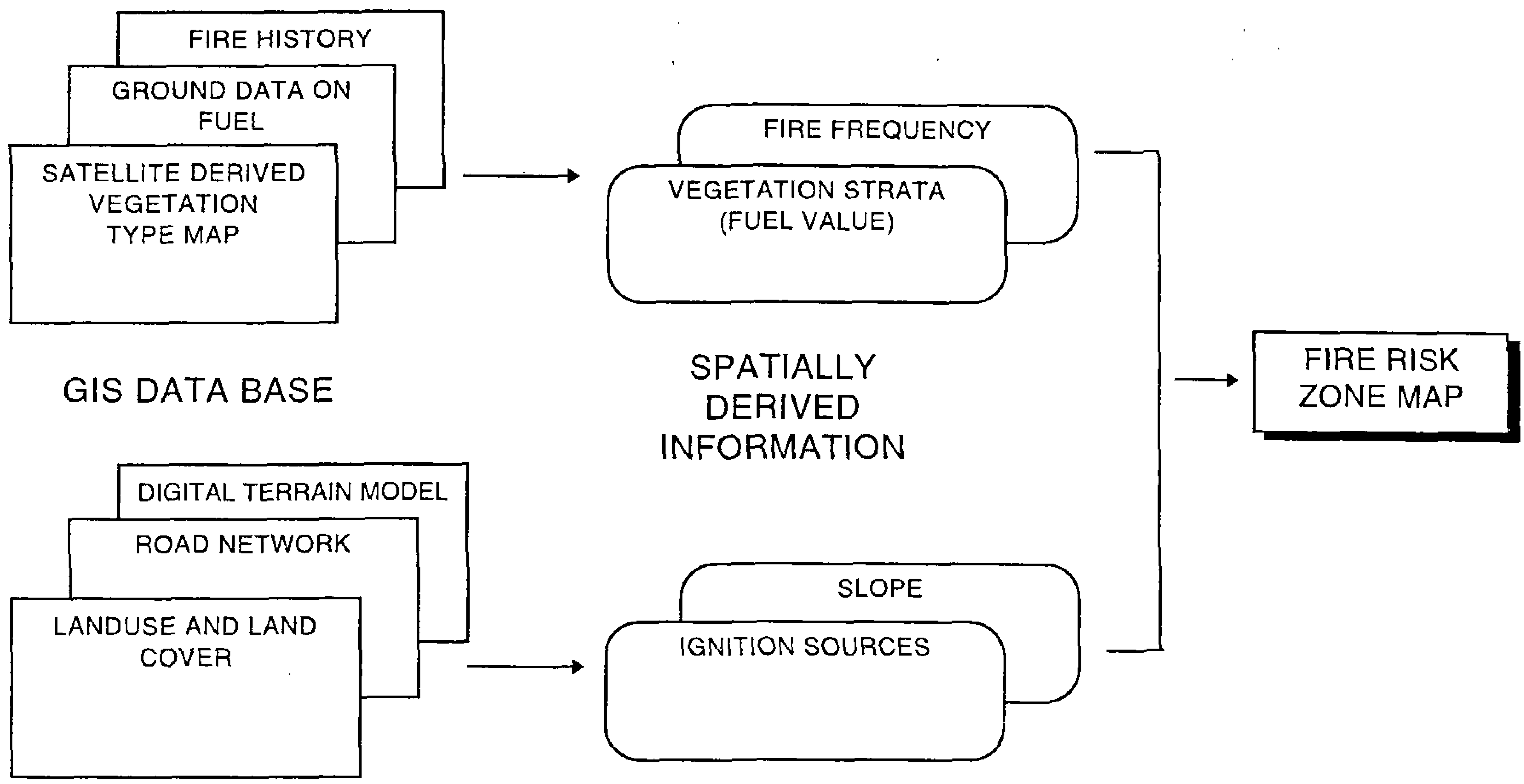


**Figure 6.** Approach to fire risk modelling.

**Table 2.** Weights and ratings assigned to variables and classes for fire risk modelling

| Variables | Classes | Ratings | Fire sensitivity |
|---|---|---|---|
| Vegetation (weight = 10) | Miscellaneous | 10 | Very high |
| | Plantation | 9 | High |
| | Mixed Sal | 8 | High |
| | Chir-pine | 8 | Moderate |
| | Miscellaneous with slope grasses | 7 | Moderate |
| | Chir-pine with slope grasses | 7 | Moderate |
| | Sal | 7 | Moderate |
| | Riverine | 3 | Low |
| | Scrub | 1 | Low |
| | Agriculture | 1 | Low |
| Habitation (weight = 5) | <1000 m corridor | 10 | Very high |
| | 1000–2000 m | 8 | High |
| | 2000–3000 m | 6 | Moderate |
| | >3000 m | 1 | Low |
| Road/fireline (weight = 5) | <100 m corridor | 10 | Very high |
| | 100–200 m | 8 | High |
| | 200–300 m | 6 | Moderate |
| | 300–500 m | 4 | Moderate |
| | >500 | 1 | Low |
| Slope (weight = 3) | 0–5° | 3 | Low |
| | 5–20° | 5 | Moderate |
| | 20–45° | 6 | High |
| | >45° | 10 | Very high |

risk was sorted in the following order: Vegetation, accessibility to the area, road/fire line network and slope[9]. The ground characteristics of the previously fire-affected area and the opinions of field experts and the existing literature[7,13] were considered, in the two-way approach in order to assign the appropriate weightage to these factors. A higher weightage indicates that the influence of the factor is high for fire risk. The considered factors were then classified into different classes at a secondary level. The different classes for each layer were then rated for their risk as per the two-way approach (Table 2). The types were rated on a 1–10 scale.

During analysis, vegetation was given the highest weightage because even though the fire environment may be favourable, forest fire cannot occur unless there is inflammable material. Each class of forest type was rated as per the fuel material found in these classes[14]. The presence of middle-level fuel, i.e. herbs and shrubs, which contributes to intensification of fire and thus enhance the risk of fire was also considered while deciding the ratings.

Accessibility to human activity is a key variable for predicting the probability of an ignition, though it does not influence the behaviour of a fire. The proximity factor was assigned the second highest weight as the influence of anthropogenic actions is the main cause for initiation of the forest fires. Roads, trails and firelines inside the forest is the possible routes for promenaders. Therefore road/fire line variables were assigned equal weights. The zone in close proximity of the settlement location point was assigned a higher rating. The risk factor decreased away from these features.

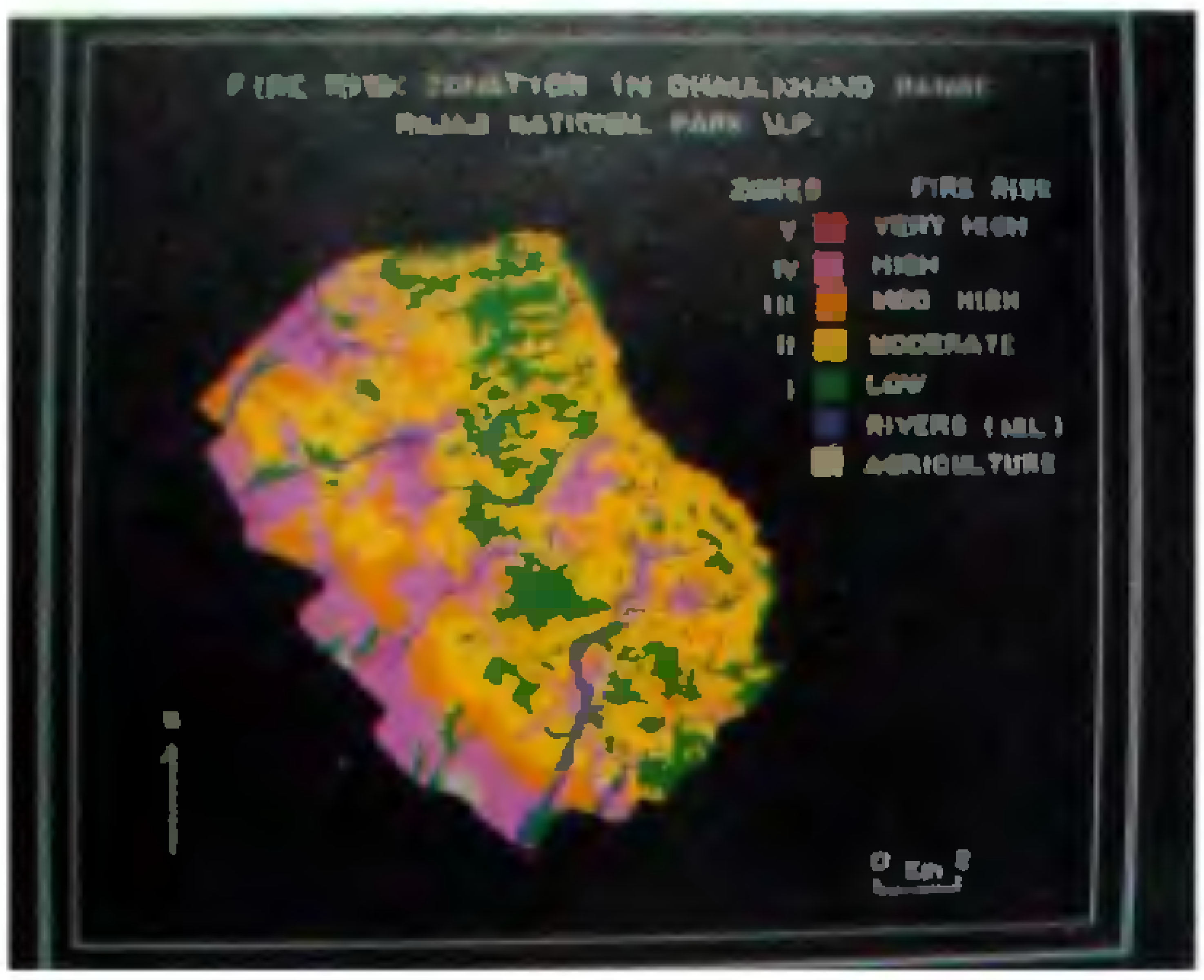


**Figure 7.** Map showing the fire risk zonation of the study area.

Slope, which does not necessarily influence the probability of an ignition but has a strong influence on the behaviour of fire, was assigned less weight. The different slope classes were rated according to the sensibility of the fire spread after the ignition of fire. Besides influencing fire behaviour, slope also plays its role in the suppression operation. Therefore the slope class, >45° was assigned a higher rating.

These derived variables taken as independent layers were overlaid in order to define fire risk levels within the study area. The equation used in GIS for the fire risk modelling and mapping the fire risk areas is as follows:

$$\mathrm{FR} = [10V_{i=1\text{-}10}\,(5H_{j=1\text{-}4} + 5R_{k=1\text{-}5} + 3S_{l=1\text{-}4})],$$

where FR is the numerical index of fire risk, $V$ is the vegetation variable (with 1–10 classes), $H$ indicates proximity to human habitation (with 1–4 classes), $S$ indicates slope factor (with 1–4 classes) and $R$ is roads/fire line factor (with 1–5 classes). The subscripts $i$, $j$, $k$, $l$ indicate subclasses based on importance in determining the fire risk.

The fuel load in different vegetation types was considered to be a multiplying factor, while calculating the fire risk in the model. The anthropogenic factors which decide the fire initiation and the slope, considered to be a factor influencing the spread of the fire, constituted the average risk $(5H_{j=1\text{-}4} + 5R_{k=1\text{-}5} + 3S_{l=1\text{-}4})$ of fire initiation and its spread. This average risk has been multiplied by the fuel load to get the fire risk. The resulting values ranged from 0 to 9000 for the study area.

During this study we have attempted to integrate the spatial data layers to obtain a single fire risk index, which could be used for mapping fire risk areas. The fire risk zone map was obtained after reclassifying the fire risk index into five classes (Figure 7).

The model seems to define a reasonably good approach for the Indian conditions, where a major part of the protected forests are still encroached by the population, thus pushing forests beyond their carrying capacity. The earlier approaches have tried to zonate the area either on the basis of hazard, which is more related to fuel[9] or both fuel and ignition sources[8]. The National Fire Danger Rating System followed by United States Forest Service uses three important primary criteria – occurrence index, burning index and fire load index to

**Table 3.** Areal extent of fire risk zones and actually affected area

| Fire risk zone | Degree of fire risk | Description of the risk zone | % share in total area | No. of points previously burnt | % share in burnt area |
|---|---|---|---|---|---|
| I | Low | Areas with low fuel load, high ignition value, and low – moderate spread value | 20.71 | 3 | 26.56 |
| II | Moderate | Areas with moderate to high fuel load, moderate to low ignition value and low to moderate spread value | 19.90 | 4 | 31.95 |
| III | Moderately high | Areas with high fuel load, moderate ignition value and moderate to high spread value | 6.67 | 6 | 26.31 |
| VI | High | Areas with high fuel load, high ignition value and high – very high spread value | 35.67 | 4 | 15.18 |
| V | Very high | Areas with very high fuel load, high ignition value and moderate to high spread value | 10.63 | – | – |
| Rivers and roads | Nil | Areas with nil fuel load | 6.40 | – | – |
| Agriculture | Nil | Areas with moderate fuel load but less prone to fire | 1.29 | – | – |

map forest fire-prone areas[10]. However, the 'fire risk' in the present study reflects both the likelihood of ignition and the risk of likely spread. The slope factor which influences the spread of fire, thus increasing the fire risk has been incorporated in the present model. An interesting feature of this model is that it explains the important fact that, with the low availability of inflammable material, the probability of the fire in the forest would be low, irrespective of other factors being favourable. Table 3 describes the resultant fire risk zones and the corresponding degree of fire risk.

Finally the fire risk zone map, was compared with the actual sites disturbed by the fire. It was observed that fire occurrence shows a definite pattern. It was found that the starting points of fire were concentrated in areas adjacent to settlements, roads, trails, etc. It was interesting to note that most of the points representing the history of past fires occurred on the very high and high risk zones predicted from the present model (Table 3). Out of 17 sites previously burnt during 1985–1993, 41.49% of the total burnt area fell in the high and moderately high risk zones, while 31.95% fell in the moderate risk zone. This agreement between the predicted risk areas and the actual affected sites was assumed to be a major test for the reliability of the present approach.

The annual incidence of forest fire often causes irreversible damage to the environment, loss of regeneration status and even at times total loss of the vegetation cover along with the increase in the rate of soil erosion. It is therefore imperative to keep regular record of all the important factors influencing the forest fire in order to enable planners to draw up protection programs. The approach to this is to prepare fire-prone zone maps of the study area, which would indicate the probability of the fire incidence and extent of its spread. The resulting risk map would help authorities in taking remedial measures against fire incidence.

The present approach combining field observations, remote sensing and GIS seems to be reliable and satisfactory for fire risk zone mapping. The work can also be carried out on other commercial GIS softwares like ArcInfo and Modular GIS environment (Intergraph – MGE). The present approach does not account for the data on aspect, fire weather and many of the remotely sensed data of fine resolution. More interesting and reliable results can be obtained when the data on these aspects will be available.


1. Matson, M. and Holben, B., *Int. J. Remote. Sens.*, 1987, **8**, 509–516.
2. Bolin, B., Doos, B. R., Jager, V. J. and Warrik, R. A., *The Greenhouse Effect, Climatic Change and Ecosystems*, Scope 29, 1987.
3. Miller, W. and Johnston, D., Pecora X symposium, 1985, pp. 305–314.
4. Muirhhead, K. and Cracknell, A. P., *Int. J. Remote Sens.*, 1985, **6**, 827–833.
5. Matson, M., Schneider, S. R., Aldridge, B. and Satchnell, B., NOAA Technical Reports, NESDIS, Washington, DC, 1984.
6. Tiwari, A. K., in *Wildlife Habitat Evaluation Using Remote Sensing Techniques* (eds Kamet, D. S. and Panwar, H. S.), Indian Institute of Remote Sensing and Wildlife Institute of India, Dehradun, 1986.
7. Champion, H. G. and Seth, S. K., *A Revised Survey of the Forest Types of India*, Manager of Publications, Govt. of India, New Delhi, 1968, pp. 100–101.
8. Kandya, A. K., Kimothi, M. M., Jadhav, R. N. and Aggarwal, J. P., Scientific note SAC/RSAG-LRD/SN/02/93, 1993.
9. Chuvieco, E. and Congalton, R. G. *Remote. Sens. Environ.*, 1989, **29**, 147–159.
10. Deeming, J. E., Burgan, R. L. and Cohen, J. D., *The National Fire Danger Rating System*, US Department of Agriculture, Forest Service, Ogden, 1978.
11. Brown, A. A. and Davis, K. P., *Forest Fire: Control and Use*, McGraw-Hill, New York, 1973.
12. Artsybashev, E. S., *Forest Fire and their Control*, Oxonian, New Delhi (First ed. in Russian, 1974), 1983.
13. Gupta, R. K., *The Living Himalayas*, Today and Tomorrow's Publishers, New Delhi, 1983, vol. 1, p. 378.
14. Lorimer, C. G., in *Introduction to Forest Science* (ed. Young, R. A.), John Wiley, New York, 1983, pp. 357–377.


ACKNOWLEDGEMENTS. We thank Prof. B. L. Deekshatulu, Director, National Remote Sensing Agency, Hyderabad and Prof. S. K. Bhan, Dean, Indian Institute of Remote Sensing, Dehradun for providing all facilities required for the study.

Received 9 November 1995; revised accepted 11 April 1996

# Biochemical degradation of the cuticular membrane in an early Cretaceous frond: A TEM study

**H. K. Maheshwari and Usha Bajpai**

Department of Palaeophytic Evolutionary Botany, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

**Ultrastructure of the cuticle of a fossil pteridospermous leaf *Thinnfeldia indica* has been investigated under the TEM. The cuticle of the leaf, which is infested with fungal hyphae, shows various stages of degradation, possibly due to activity of an enzyme secreted by the fungal hyphae.**

AERIAL parts of the terrestrial plant body are generally covered by a thin continuous layer – the cuticular membrane or the cuticle. The cuticular membrane comprises an inner layer of cellulose encrusted with cutin, and an outer cuticularzied layer or the cuticle proper. The cuticular membrane is covered on the outer side by an irregular deposit of semi-crystalline or crystalline material[1]. Cutin is an insoluble high-molecular weight, complex lipid polyester[2,3].