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REMOTE SENSING AND GIS APPLICATIONS IN FIRE ECOLOGY

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Fire can be seen as just another factor in an environment, such as flods, hurricanes, drought, etc. However, unlike all these physical factors, fire is itself influenced by the biota or partly by the vegetation. Evidences indicate that natural fires caused by lightning, volcanoes, meteors, etc., must have interfered tropical vegetation through all stages of evolution. But, it is only since man learnt the use of the fire that permanent changes in many tropical ecosystems have occurred. The main influence has been through the method of cultivation called `shifting cultivation' involving mainly of slash and burn.

Recent developments in the use of satellite observation technology have led to new insights into the dynamics of vegetation communities and of large-scale disturbances occurring therein. In particular, data derived from thermal sensors carried on board space platforms have provided regular information on the occurrence and distribution of fires in the tropical and sub-tropical ecosystems.

Many studies on the role of fire on vegetation communities have been extensively carried out all over the world, but only recently the global view of the phenomena have been acquired directly through remote sensing. Satellite data provides that additional information on fire distribution and on ecological interactions leading to vegetation burning.

It is evident that an external source is always required to start a fire. These sources could be either natural or anthropogenic. Crutzen and Andreae (1990) have estimated that the natural sources of fire accounts for about 10 % of the world's total biomass burning. Therefore, it is essential to estimate the frequency of such fires in a region or a habitat. Some of the causes of such fires are lightning strikes, volcanic actions, frictions caused by tree branches, and other rare phenomena that are regional.

In today's world scenario, the human-induced fires are far more significant than the natural source. The human-induced fire falls under 3 categories:

1.Fires that are set deliberately for clearing the path, hunting, and grazing. In tropical countries, these have specific applications, such as, thatching materials (*Dipterocarpus* sp.), extraction of wood oil (Eucalyptus sp.) and honey, stimulating better growth in leaves *(Diospyros melanoxylon)*, which are used for wrapping cigarette (`Bidi') in India (Stott *et.al.,* 1990).

2.Fires that are set outside a forest ecosystem, such agricultural land, which can then get out of hand and spread into the neighbouring habitat, such as, forests. Seiler and Crutzen (1980) estimated that around 40 x 10^6 ha/year of forested area are cleared due to shifting cultivation alone.

3.Purely accidental fires, which derive from a variety of causes, in the tropics, many different people crossing the forest for hunting, for pasture land, gathering forest products, migrants, campers, etc., clearly result in high probability of accidental fires. Slott *et al.* (1990) claimed that *c* 66 % of Thailand's forest fires are caused accidentally by people crossing the forests.

Fuel for fire

Large woody materials, such as trees, shrubs, fallen logs are often the sources of fire. Human actions, such as logging, cutting, etc., may render these fuels more flammable by reducing their size, volume and distribution. Therefore, secondary forest or logged forests are more prone to fire (Goldammer, 1991). In heavily logged forest, the trees become widely-spaced. As such, the shrubs fill the gaps and provide a ready fuel for fire. Also, sometimes, these woody trees contain extractive materials, such as resins, gums, aliphatic and aromatic hydrocarbons, etc., which can be highly flammable; thus, making it more susceptible to fire. Climbers and epiphytic plants also play a vital role in spreading the fire both horizontally and vertically. Some of the other fuels include the living biomass and fallen litter, which contain a wide range of smaller woody materials, which together represent a sizable and more flammable fuel supply. Litter includes the most potential fuel lying loosely on the surface of the ground, such as broken twigs, fallen leaves, flowers and fruits. Grasses represent the most important combustible material in most of the tropical ecosystems (Sarimento, 1985). Yadava (1990) worked in the savannas of North-East India, and found that the grasses, *Imperata cylindrical* and *Brothricochoa intermedia* dominate the above-ground biomass. These are some of the highly fire-prone areas. Apart from grasses, the herbs and ground vegetation can also be a potential source of fire. Singh and Yadav (1974) have shown that for certain savannas in North India, there are upto 40 species of herbaceous plants, of which, 30 are annual plants in a 2 ha plot. In some of these habitats, the most important species are not grasses, but two annual weeds, viz., *Kochia indica* and *Chenopodium album*, which together comprise *c* 36 % of the total biomass.

Factors of fire

The probability of a fire occurring at a particular space and time depends on the following factors:

1.Climate: Macro-climate is temporarily variable but spatially fairly constant; while, micro-climate is variable temporarily as well as spatially.

2.Abiotic factors: Such as, topography, soil type, etc., are spatially variable but temporarily constant.

3.Biotic factors: Fuel load, e.g., vary over time scales, while flammability varies with the spatial changes.

Features of fire

1.Spread: Fire spreads horizontally by igniting a series of particles of fuel at or near its edge. The factors that influence the spread are:

(a)Wind
(b)Topography
(c)Fuel continuity

2.Intensity: It is the rate at which the fire releases heat. It can be determined by the amount of heat energy produced. Fire intensity is related to the length of the flame. Factors influencing intensity are:

(a)Available fuel
(b)Moisture and temperature
(c)Chemical factors
(d)Wind
(e)Topography

Fire regime

Fire regime can be defined as the description of a particular fire. It also represents the characteristics of the fires that typically occur at a site. Understanding the fire regime of a burned area is extremely important as it gives an insight into the impacts caused by the fire (Gill, 1981). The features that constitute the fire regime are:

1.Fire frequency: time between fires
2.Season of burning
3.Extent of fire: patchiness of the burn
4.Type of fire: ground, surface or crown fire

Fire in seasonal forest

The length and the intensity of dry periods in the tropics increase with the distance from the pre-humid equatorial zone (Goldammer, 1991). The forests gradually develop to more open, semi-deciduous and deciduous formations, such as, moist and dry deciduous forests and monsoon forests. In closed deciduous forests, the fuel will be from the tree layer unlike in the savannas where the grasses are the only fuel. The term `forest' is, therefore, used, if trees and the tree residuals are the fuels (Goldammer, 1993). The main seasonally available fuels in these forests are the herb layers, grasses, shed leaves, twigs, etc. This allows the under storey shrubs and the trees to survive and take advantage of the regular intervals of fire. The trees will also be well adapted to fire in this region having a thick bark, ability to heal fire scars, dormant buds, seed characteristics, etc.

During the dry season, deciduous trees shed their leaves and provide the surface fuel. In addition, the dried grass layer together with the shrub layer adds to the fuel. The forest users mainly set the fires, usually to remove the dead plant materials on the ground, to stimulate plant growth and to improve harvest of other forest products. Fires of low fuel loads usually develop as fires of moderate intensity and tend to spread over large areas of forest. High intensity of fire has been reported in the tropical savannas of Australia by Gill (1998). In some cases, fire may affect the same area twice in a year. For example, one in early dry season, where the fire consumes the grass layer, and one in subsequent fire, where it burns the shed leaves and litter layer (Goldammer, 1993). This happens because of the uniformity of fuels, where the fires frequently escape their intended boundaries.

The ecological impact of yearly fires on deciduous and semi-deciduous forest formations is significant. Fire tolerant trees replace the species potentially growing in an undisturbed environment. Many of the monsoon forests of Asia would be re-converted to evergreen forest biomes if human induced fires are eliminated (Blasco, 1983). For a long time, fire adaptations and the possible fire dependence of economically important trees, such as Teak (*Tectona grandis)* and Sal *(Shorea robusta)* have been the focus of a controversial discussion regarding the traditional fire-control policy in British Indian Forestry (Pyne, 1990).

Therefore, protection from forest fires needs to be addressed from both the technological and methodological points of views. One such technique is by the use of Remote Sensing. Remote Sensing from space is especially suitable for forest fire studies. The wide area that they cover, the high frequency provided by satellite sensors, and their valuable information on the non-visible region of the spectrum, makes them a potential tool for preventing, detecting and mapping the forest fires. Over the last decade, the use of satellite remote sensing has increased tremendously, making it an important component in forest fire strategic plans.

Some of the satellites and the sensors which are used in fire studies are as follows:

1.National Oceanic and Atmospheric Administration (NOAA): This satellite is accompanied by the Advanced Very High Resolution (AVHRR). The AVHRR sensor has a low spatial resolution of about 1100 m. This has a set of five spectral bands between the visible and infra-red regions of the electromagnetic spectrum

2.Landsat 5 Thematic Mapper : This is specifically used for vegetation studies. This has a very good spatial resolution of 30 m and consists of 7 spectral bands. Band 1 – Blue, Band 2-Red, Band 3- Green, Band 4- Near Infra-red, Band 5-7-Mid-Infra-red, Band 6-Thermal Infra-red.

3.Indian Remote Sensing Satellite (IRS- IC/ID): Having the sensors Linear Imaging and Self-Scanning Sensors (LISS III) on board are widely used for various natural resources applications, including fire studies, all over the world. Its high spatial resolution of 23.5 m and frequent passes for a low cost, make it conducive for various fire-related studies. This is a Multi-Spectral Scanner (MSS) and possesses five bands, viz., Band 1: Blue, Band 2: Green, Band: Red, Band 4:Near Infra-red (NIR), Band 5: Short wave Infra-red (SWIR). The bands NIR and SWIR have been particularly useful in fire characterizing and mapping.

Fire studies using remote sensing observes the following steps:

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Fire studies using remote sensing observes the following steps:

1.To identify the burnt areas of a region.
2.To map these burnt areas, over a time scale or between fire seasons in a single year. This effectively requires both Multi temporal and multi spectral images.

1, Spectral characterization of burnt areas:

Spectral properties of recent burns are characterized in the visible, near infra-red, mid infra-red, thermal infra-red and microwave spectral domains. Fire-induced reflectance changes can also be compared for various ecosystems and the ecological effects of the phytomass combustion can be obtained.. In the year 1999, Pereria *et al.,* had analysed a series of colour composite images of Landsat Thematic Mapper^{TM} data, and illustrated the appearance of burnt surfaces in the various tri-spectral spaces, in contrast with the healthy forests, agricultural land and urban areas. Temporal evolution of these spectral characteristics of the burnt aeas were also shown using the 5-year time series of Thematic Mapper images of two coniferous forest burns in Portugal. This gave distinctive spectral properties of the burned surfaces that can be used to discriminate and map burnt areas.

Acording to Robindon (1991), there are basically two types of post-fire signals, one is the charred surface after fire, and the other is the alteration in vegetation structure depicted by the fire scars. The first signal is unique and does not last for a very long time. The second signal, however, is more stable. But, it is not very significant to discriminate fire effects as the gap within the forest could be attributed to other factors as well such as, grazing, felling, etc.

The visible, NIR and MIR regions of the spectrum was used and various combinations of composite images were generated. The results, thus obtained, were as follows:

1.In the visible region, recent burns tend to be darker than the surrounding forest type in a tropical forest.
2.In the NIR region, the brightness of recently burnt areas is lower than the corresponding area.
3.Spectral response to fire in the MIR is similar to that in the visible region, where the burns tend to be darker that the forested areas.
4.The NIR provides the best discrimination ability to burnt areas.
5.The visible region is not good enough for identifying the burnt areas, as it confuses with the other land cover types that appear dark in this spectral domain.
6.The MIR region is also relatively good for the detection of burnt areas and it is less sensitive to atmosphperic disturbances.
7.Thus, the NIR/MIR bispectral space has a stronger ability to identify the recently burned areas, than the NIR/Visible space.

This study also revealed that burnt surfaces show ecological effects of fire, which, in turn, affects the greenness, albedo, temperature and soil moisture.

In case of IRS images with LISS III sensor, the NIR and SWIR bands have been used for identification of burnt areas.

2.Burnt area mapping

Chuvieco *et al.*(1999), developed an algorithm in order to map burnt areas in lberia during 1991 and 1994 fire seasons. This algorithm was multi temporal image composite algorithm. They used the Global Environment Monitoring Index (GMI), albedo and surface temperature, for mapping the burnt areas of 1991 fire season. A classifier was obtained from the training data, using the classification of Regression Trees (CART) algorithm. For the 1994 session, a new spectral index was designed to detect burnt areas. This helped in identifying clearly burnt pixels and to avoid errors. Later, a distance-based multicriteria analyses technique was applied to map the burnt areas. This involves a combination of spatial closeness and spectral similarity. This method detected 80% of forest fire larger than 1000 ha and proved effective in mapping burnt areas.

Kasischke and French (1995) used AVHRR image to map burned areas of Alaska during the years 1990-91 fire session. They developed two Normalised Difference in Vegetation Index (NDVI) images for the pre and post fire season, and they also developed two sets of Maximum Value Composites (MVC). Burnt areas were identified based on those pixels having a NDVI less than threshold value. Or having a decrement larger than 0.2. The NDVI differencing turned out to be better than the MVC differencing. This way of estimating and mapping burnt areas had an accuracy of about 97 %. This method where, using vegetation Index differentiation between pre-season and post-season of burns, rather than the multi-temporal composite differencing was further proved by Martin and Chuvieco (1995).

There are various other techniques to map the burnt areas on a local or regional level. In order to achieve this, a high spatial resolution satellite, such as Landsat TM or IRS LISS-III images needs to be used. One such widely used technique is the Spectral Mixing Analysis (SMA). This technique also depends on the type of data that is used such as multi-temporal data or a single post-fire data.

Spectal mixing analysis (XMA)

SMA, also known as spectral unmixing, has been used in remote sensing to counteract the problem of mixed pixels. It assumes the fact that the spectral difference found on the image at the pixel level is a result of a mixture of smaller components with differing spectral behaviour (Caetano *et ala.,* 1994). SMA effectively extracts pure spectral signatures from such features at pixel level, and expresses them in concentrations of reference endmembers (Pereira, 1997). The output is a fraction image for each endmembers and the error is also provided. This method involves, three steps, viz., model building, model fitting, and fraction image editing.

SMA has been quite successful in to study burnt areas using Landsat TM and NOAA-AVHRR (Caetano, 1994, 1996). Using Landsat TM, a spectral mixing model was developed from both the burnt aea and fire severity mapping. This converts the TM channels into proportion of soil, unburnt and burnt vegetation at a sub-pixel level. The same principle can be employed in case of the IRS image. Being a multispectral data and also having a very high resolution, this technique would be effective in categorizing the burnt areas of a region. This is also helpful in studying the fire ecology of a local aea such as districts or a forested belt.

Ranganath *et al.* (1994) used temporal IRS data to analyse the forest fire incidence, extent of burnt area, and the vegetation types affected in Rajiv Gandhi National Park, Nagarhole, Karnataka, India. A model was also developed to identify and delineate fire prone regions by integrating the related parameters. Basappanaver *et al* (1993), carried out similar studies in Bandipur and Nagarhole National Parks of Karnataka, India. They monitored and mapped forest fires using IRS-1A and 1B data. They classified the image by a method known as supervised classification wherein, using the information regarding the burnt areas from the ground, the image was classified into burnt and unburnt areas.

Conclusion

Forrest fire, be it natural or human induced, can have either a positive or negative effect on the ecosystem. It can affect the vegetation structure, its functions, and their succession. But the increased number of forest fires that are occurring in increased frequency, in a particular area in an ecosystem, can constitute a possible threat to the ecosystem. Therefore, it is highly essential to understand the consequences of fire activity; and, hence, to develop a well-structured Decision Support System (DSS) for the efficient management of forest fires. This requires the development of a comprehensive information system that enables suitable monitoring processes.

Remote sensing could be used effectively for the burnt area mapping, as it provides the necessary information of the earth's features on an economical and timely fashion. Multi-spectral high resolution data, acquired periodically, in the visible and infra-red region of the electro-magnetic spectrum, provide essential source of information on fire characteristics. This information, backed by proper computer-aided processing and interpretation, contribute to a better, cost-effective, and time-saving method for monitoring fire-affected areas.

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Selected References

Crutzen, P.J. and Andreae, M.O.(1990). Biomass burning in the Tropics: Impact on atmospheric chemistry and biogeochemical cycles. Science, 239, 1669-78.

Goldammer, J.G. (1991). Editor: Fire in the Topical Biota: Ecosystem processes and Global challenges, Berlin: Springer-Verlag.

Goldammer, J.G. (1993). Historical Biogeography of Fire: Tropical and Sub-tropical. Fire in the Environment: The ecological, atmospheric and climatic importance of vegetation fires. Editor: Crutzen and Goldammer, 1993. John Wiley and Sons Inc.

Gill, A.M. (1998). A hierarchy of fire effects: Impacts of fire regimes on landscapes. 3rd International Conference on Forest Fire Research, Vol. I: 129-144.

Periera Jose, M.C. and Ana, C.L. (1999). Spectral characterization and discrimination of burnt areas. Remote sensing of large wildfires in the European and Mediterranean basin, Ch 7: 123-138.

Ranganath, B.K.; Diwakar, P.G.; Adiga, S.; and, Radhakrishnan, K. (1994). Application of Remote sensing and GIS in Forest fire Analysis

Singh, J.S. and Yadava, P.S. (1974). Seasonal variation in Composition of plant biomass and net primary production of a tropical grassland at Kurukshetra, India. Ecological Monographs 44: 351-376.

Yadava, P.S. (1990).Savannas of North-East India. Journal of Biogeography 17: 385-94.