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Generation of division-level fire maps
using satellite-derived fire data

A method for the rapid generation of division-level fire sensitivity maps using satellite-derived fire data to aid effective management of forest fires.

Effective control over forest fires demands that the scarce men and material resources to detect and douse these fires are utilised in the most optimal and efficient manner. Creation of division-level fire maps is an extremely crucial exercise in this cause, since they facilitate the analysis of the efficacy of the current deployment of fire-fighting resources, and also guide the redeployment of these resources to those regions that need them the most. In this paper, we describe the creation of division-level fire maps by utilising satellite-derived fire data from the NASA FIRMS (Fire Information for Resource Management System) database, together with the GPS coordinates of the fire-fighting resource bases. The process utilising freely available data is simple and scalable, and can be extended to any other region with ease. It permits the prompt recognition of fire hot-spot regions and an analysis of the fire-fighting resource bases, so vital for supervisory and management purposes.

Key words: Forest fire, Fire map, Fire monitoring, Planning, Management.

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Introduction

Our forest resources are constantly being threatened by several agents of disturbance, one of which is forest fires. According to the India State of Forest Report, as much as 64.29% of our forest cover falls under various fire incidence classes, and only 35.71% of our forest cover falls under theno fire incidence class (FSI, 2015). Forest fires have large conspicuous impacts over forest cover, biodiversity and wildlife. Besides, they also have several short term and long term impacts on soil, including charring, changes in soil colour and texture, (Ulery and Graham, 1993) changes in soil chemistry and enzymatic activity (Giovannini *et al.,* 1988; Kutiel and Shaviv, 1989; Covington *et al.,* 1991; Covington and Sackett, 1992; Parra *et al.,* 1996; Giovannini and Lucchesi, 1997; Fernández *et al.,* 1999; Boerner and Brinkman, 2003), changes in pH, microbial community and hydrophobicity Bissett and Parkinson, 1980; Fritze *et al.,* 1993; Bååth *et al.,* 1995; Fonturbel *et al.,* 1995; Choromanska and DeLuca, 2002; Certini, 2005), alterations in humus (Almendros *et al.,* 1988; Almendros *et al.,* 1990; Almendros *et al.,* 1992; González-Pérez *et al.,* 2004), effects on runoff ((Kutiel *et al.,* 1995; Inbar *et al.,* 1998), timber supply (Wagner, 1983; Martell,1994; Armstrong, 2004), and the ecosystem as a whole (Campbell *et al.,* 1977; De Bano *et al.,* 1998; OBRIST *et al.,* 2003; Wardle *et al.,* 2003).

We have several fire control mechanisms, from simple beating of fires to complex counter firing techniques, fire lines and fire breakers . We also have numerous rapid forest fire detection approaches, utilising satellites (Flannigan and Haar, 1986; Jaiswal *et al.,* 2002), unmanned aerial vehicles (Zhou *et al.,* 2005; Casbeer *et al.,* 2006; Alexis *et al.,* 2009; Merino *et al.,* 2012) and wireless sensor networks (Yu *et al.,* 2005; Son *et al.,* 2006; Zhang *et al.,* 2008; Hefeeda and Bagheri, 2009; Lloret *et al.,* 2009). However, effective control over forest fires also requires prior adequate planning, necessitating the creation of forest fire maps. These maps can depict the areas that are frequently affected by forest fires, enabling the concentration of resources on those spots for prompt action when the next fire strikes. They can also include a depiction of our existing fire-fighting resource base, permitting an analysis of their adequacy and the changes that are required.

Fire maps of forest divisions can easily be prepared by mapping the yearly fire incidence on transparent maps of the division, preferably by shading it compartment-wise or beat-wise, and then stacking them on top of each other. In this way, the compartments that have not suffered any fire in the last few years will look transparent, while the shade will turn darker as the number of fire incidences increases. Traditionally, the fire incidence raw data has been taken from the reports sent to the divisional headquarters by the range officers. However, it is also possible to utilise satellite-derived fire incidence data for the same purpose, with the added advantage that it is unbiased, and already available in a computer-processable format, thus simplifying the process of cartography. NASA FIRMS (Fire Information for Resource Management System) is a system developed by the University of Maryland that provides expeditious near real-time active fire locations, utilising data acquired from the MODIS (Davies *et al.,* 2009; Justice *et al.,* 2010; Giglio *et al.,* 2016) instrument on board Terra and Aqua EOS satellites, and the VIIRS (Schroeder *et al.,* 2014) instrument on board the SNPP satellite. Fires are detected by exploiting the strong emission of mid-infrared radiation bythem. Active and archival fire data is made available freely on the NASA FIRMS portal (https://firms.modaps.eosdis.nasa.gov).

In this paper, we describe the process of creating a fire map for an area utilising the archival data of NASA FIRMS database, together with the GPS coordinates of fire-fighting resource bases in the form of fire watch towers. The process is simple and scalable, and can be extended to any other region with ease. It permits prompt recognition of the fire hot-spot regions and an analysis of the fire-fighting resource bases, useful for supervisory and management purposes.

Material and Methods

The study area

The South Balaghat (Territorial) Division of Balaghat Circle of Madhya Pradesh was chosen as the study area. The forests of this region belong to the categories 5A/C-1B (Southern Tropical Dry Deciduous Teak dominated Forests), 5A/C-3 (Southern Tropical Dry Deciduous Mixed Forests) and 3B/C-1(C) (Southern TropicalSlightly Moist Teak Forest) according to Champion and Seth's classification (Champion and Seth, 1968; Shrivastava, 2006; Verma, 2008). These dry deciduous forests are extremely susceptible to forest fires since the leaves are shed at the beginning of the dry season, creating a heavy fuel load on the ground for the propagation of surface fires.

Source of fire data

Archival MODIS fire data from the NASA FIRMS system was used in this study. With a 1,000 m resolution, it detects large-scale fires, automatically filtering the data for small isolated incidents of fire. The data is available freely on the NASA FIRMS portal (https://firms.modaps.eosdis.nasa.gov). The four years of 2013-2016 were chosen as the study period.

Selection of compartments with fire signatures using QGIS

The yearly fire data was vectorised and the layer so created intersected with the compartment map layer to discern the compartments that had fire signatures in that particular year. These compartments were saved as a separate layer. The process was repeated for each study year, to discern the compartments with fire signatures in each year of the study period.

Depiction of fire watch tower locations and finalisation of the fire map

Fire watch tower locations were gathered in the form of GPS coordinates from the ranges. These were plotted on the QGIS platform over the compartment map layer of the division in green colour. The yearly compartment fire layers were given red colour with 80% transparency such that upon layering on top of each other, the compartments with fire signatures over several years would become progressively deeper in colour. The map was finalised by adding the legend, the direction arrow and the scale.

Results and Discussion

Creation of yearly fire data image for the desired area

The yearly raw fire data for the area of interest downloaded from the NASA FIRMS server were processed through the algorithm described in fig. 1(a). The yearly fire data images depicted in fig. 1 (b-e) represent fire signatures as white patches on a black background (Davies *et al.,* 2009; Justice *et al.,* 2010; Giglio *et al.,* 2016).

Selection of compartments with fire signatures using QGIS

The fire data was vectorised and processed in the QGIS platform following the algorithm depicted in fig. 2 (a). Screenshots illustrating the process for the year 2013 are portrayed in fig. 2 (b-f). The process resulted in the selection of compartments that had fire signatures detected by NASA FIRMS in the year 2013, as seen in fig. 2 (f).

Depiction of fire watch tower locations and finalisation of the fire map

The fire watch tower locations gathered in the form of GPS coordinates from the ranges were plotted on the map. The layers of compartments having fire signatures for a year were progressively added to the map. Since the layers had been given 80% transparency, those

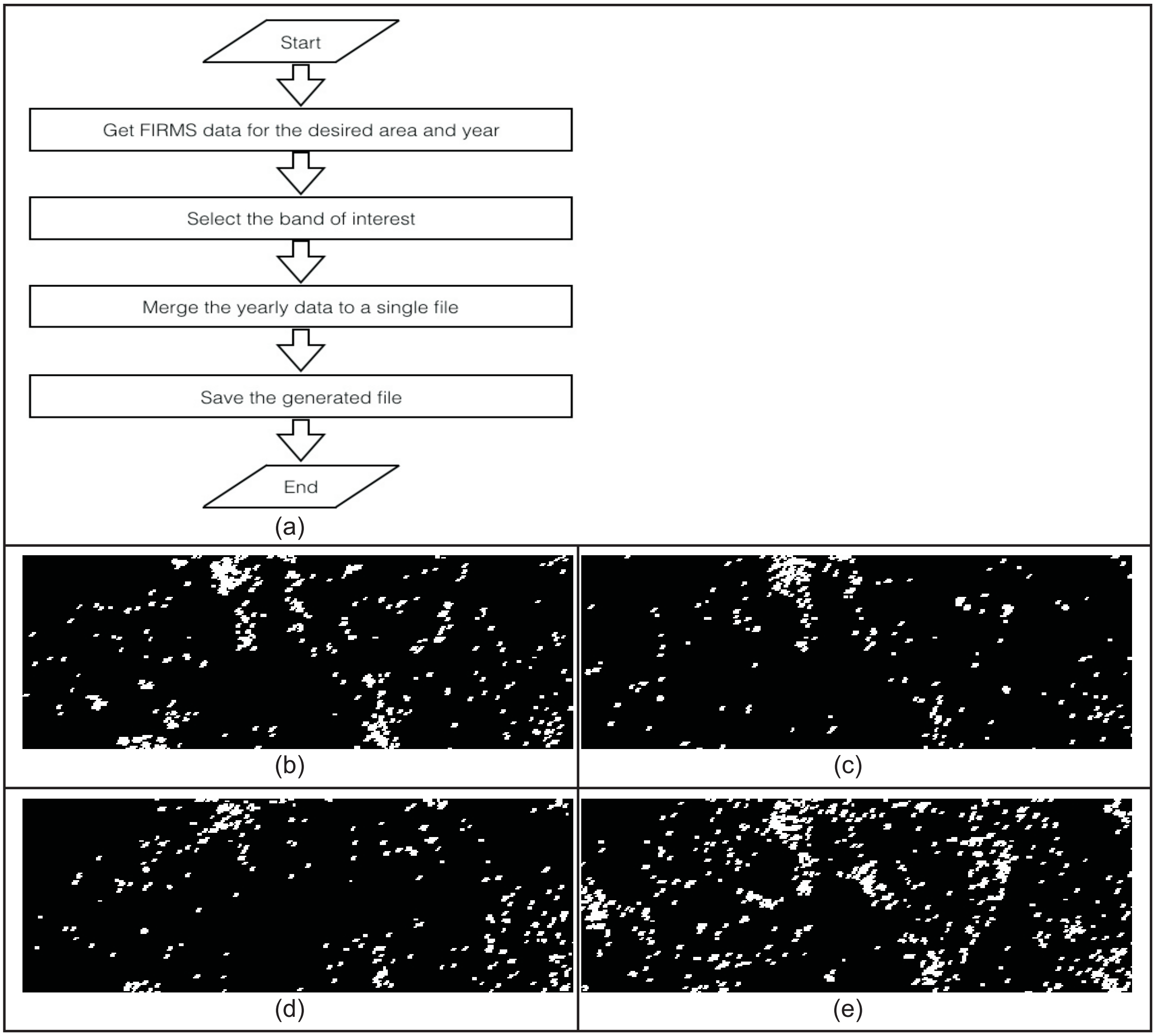

Fig. 1: Creation of yearly fire data image for the desired area. (a) Algorithm for the creation of yearly fire data images for the desired area. (b) Fire data points of Balaghat region for the year 2013. (c) Fire data points of Balaghat region for the year 2014. (d) Fire data points of Balaghat region for the year 2015. (e) Fire data points of Balaghat region for the year 2016.

compartments that had fire signatures in multiple years gradually became deeper in colour, thus representing those highly fire-prone areas that should receive preferential protection in the fire protection plan. The finalised map is depicted in fig 3.

It can be observed from the finalised map that while several fire watch towers are located in areas that are greatly susceptible to fires, there are many watch towers located in the less fire-prone South region that can easily be shifted to other locations, where their presence would serve a greater utility. On the other hand, many compartments on the North are highly susceptible to fires, having suffered from fires in all the years of study. However, they do not have any fire watch tower. Thus, the activity of plotting the watch towers and marking the fire susceptible compartments on the same map can be extremely advantageous in providing a bird's eye view of the existing situation, thus aiding in the planning process.

Generation of fire maps is an accepted technique to aid the planning process ((Bahuguna, 1999; Ministry of Environment and Forests, 2014). These maps fall in two categories, maps utilising fire incidence field data at beat level (Berar, 1932) and maps of fire vulnerability discerned through layers of data and computations regarding fuel load, wind, temperature, slope, etc. (Jaiswal *et al.,* 2002; Nami *et al.,* 2018). However, while the former category is dependent upon the accuracy and reliability of data collected by the field staff, the latter is

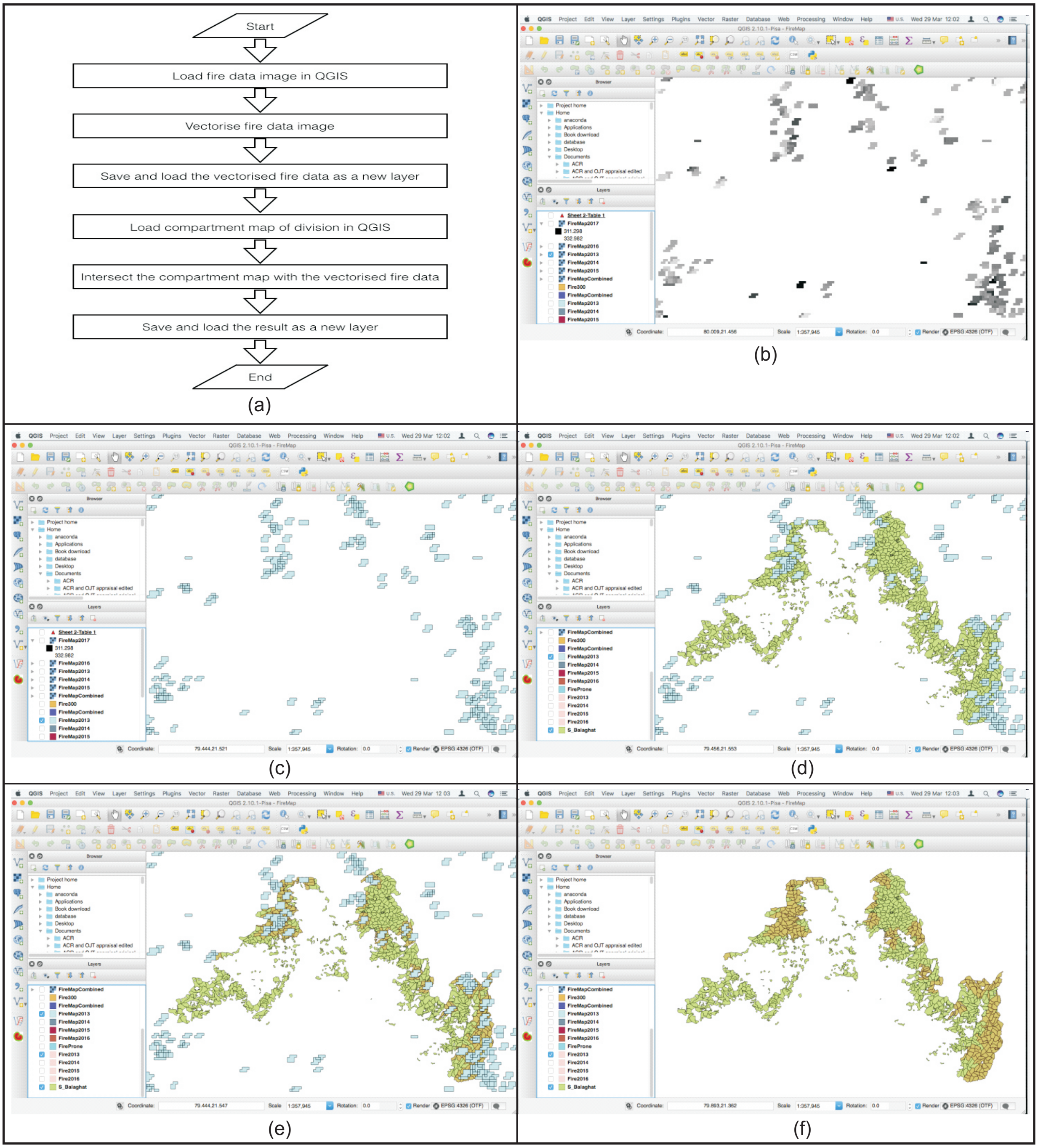

Fig. 2: Selection of compartments with fire signatures in a particular year. (a) The algorithm for selecting the compartments. (b - f) Screenshots illustrating the procedure for the year 2013. (b) The raster data of fire signatures for the year 2013. (c) Vectorised data derived from the raster image in (b). (d) The vectorised data superimposed on the compartment map layer of the South Balaghat (Territorial) division. (e) Compartments selected through the process of intersection. (f) The final result depicting the compartments that had fire signatures detected by NASA FIRMS in the year 2013.

too technical to be used by most field officers. By creating a middle path between these two categories, our protocol employs satellite-based data for high accuracy, together with a simple algorithm using free and open-source software for ease of deployment. This has the potential to bring fast and updated access to a reliable decision support mechanism to field officers, aiding in the management of forest fires.

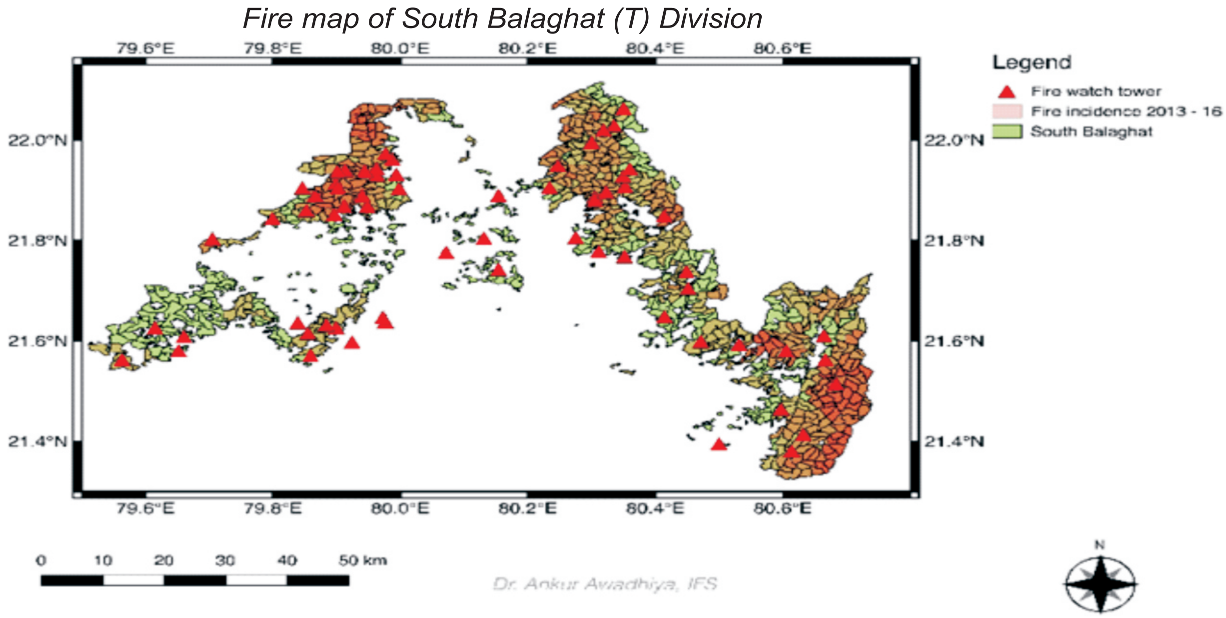

Fig. 3: The finalised fire map showing the susceptibility of different compartments to fire, together with the existing fire watch towers. Note that several watch towers are in low fire susceptibility areas, or even outside the division boundary.

सैटेलाइट-व्युत्पन्न अग्नि आँकड़ों का उपयोग करके प्रभाग स्तर पर अग्नि मानचित्रों का सृजन

अंकुर अवधिया

सारांश

वनाग्नियों के ऊपर प्रभावी नियंत्रण के लिए यह अपेक्षा है कि इन अग्नियों का पता लगाने और बुझाने के लिए पर्याप्त मानव एवं पदार्थ संसाधनों का उपयोग अधिक इष्टतम एवं प्रभावी तरीके से किया जाए। इस कार्य में प्रभाग स्तर पर अग्नि मानचित्रों का सृजन करना एक अत्यधिक कठिन प्रक्रिया है क्योंकि ये अग्निशमन संसाधनों की वर्तमान तैनाती की क्षमता के विश्लेषण को सुगम बनाते हैं और यह उन इलाकों के लिए भी इन संसाधनों के पुनराभिनियोजन में मार्गदर्शन करते हैं जहाँ इनकी ज्यादा आवश्यकता है। इस शोधपत्र में हमने अग्निशमन संसाधन आधारों के जी पी एस समन्वयकों के साथ नासा फर्मस (संसाधन प्रबंध प्रणाली के लिए अग्नि सूचना) आँकड़ा आधार से सैटेलाइट-व्युत्पन्न अग्नि आँकड़ों का उपयोग करके प्रभाग स्तर पर अग्नि मानचित्रों के सृजन का वर्णन किया है। स्वतंत्र रूप से उपलब्ध आँकड़ों को उपयोग करने की प्रक्रिया साधारण और मापनीय हैं तथा इनका आसानी से अन्य क्षेत्रों में विस्तार किया जा सकता है। ये अग्नि हाट-स्पॉट क्षेत्रों की त्वरित पहचान और अग्निशमन संसाधन आधारों के विश्लेषण का अवसर देते हैं ; जो पर्यवेक्षण एवं प्रबंध उद्देश्यों के लिए अहम हैं।

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