Mapping spatial relationship of Van Panchayats and Forest Fire of 2019 in Almora district, Uttarakhand

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Van Panchayats (VPs), i.e. forest-dependent communities in Uttarakhand, India and are the vital links between the villagers and the forests. However, the state has a consistent history of Forest Fires (FFs) that have an adverse impact on the people as well the environment. The present study was carried out to map the relationship between VPs and FFs using exploratory spatial data analysis and GIS in Almora district of Uttarakhand. Results obtained show varying degree of spatial relationship between VPs and FFs. The insights gained from the study may serve as crucial inputs for evidence-based decision making that may be helpful in bridging the gaps in the existing knowledge of forest management and designing a robust fire management policy framework for the state.

Keywords: Forest fire, forest-dependent communities, hot spots and cold spots, spatial data analysis.

PEOPLE across societies around the world depend upon forests for their livelihood, provision of clean air and freshwater, biodiversity conservation and impacting climate dynamics. However, Forest-Dependent Communities (FDCs) rely more heavily on forests. These FDCs include forest-dwellers who depend on forest resources as their primary source of food and livelihood; people residing in the vicinity of forests with agriculture as their main livelihood, and using the forests to enhance their consumption and income-generating activities. FDCs also include rural people whose main income comes from labour through forest-based commercial activities[1]. According to a global estimate, around 1.095–1.745 billion rural people depend on forests for their livelihood to varying degrees. About 200 million indigenous communities around the world are dependent on forests almost completely[2]. In India also a large number of tribal and rural dwellers are spread in and around forest areas[3] with their existence intricately linked with the forests and their

resources[3]. Thus, the role of local people as key forest stakeholders in sustainable forest management has been widely recognized. This realization has resulted in the development of a variety of generic approaches throughout the world described as collaborative management of forests[4]. These approaches though differ widely, but they have similar recognition for the necessity and practical advantages of actively involving local people in forestry activities. In Uttarakhand, India, Van Panchayats (VPs) are the vital links between villagers and forests. These VPs represent one of the biggest and most diverse experimental exercises developed in collaboration with the state to manage forests by the local communities[5]. VPs are considered as one of the earliest examples of decentralized resource management through formal state–community partnerships in the world, which have been relatively successful in managing forest resources in the region. In spite of being a classic case of a state–people partnership, these institutions are facing challenges from unrealistic and target-driven policies affecting their democratic functioning.

The stringent forest management policies, acts and constitutional safeguards have estranged majority of FDCs from the forests. As a result, the state is witnessing depletion and degradation of forest wealth[6]. A reduction of at least 147 sq. km in forest cover has been reported over a decade in Uttarakhand and the rate of degradation is also high, with the highest being in Udham Singh Nagar (128 sq. km) and Bageshwar (119 sq. km) districts[7,8]. Forest Fires (FFs) in Uttarakhand are a periodic event every year during February to June. In 2016 itself, around 2166 sq. km (approx. 9%) of the forest area was affected due to FFs[9]. Goldammer[10] identified several global issues and trends due to FFs that have an impact on the environment and societies, including population dynamics, widespread poverty due to unemployment, rural exodus and land tenure dispute, land-use changes, wildland–urban conflicts, climate change, and threats to human health, security and peace. Kodandapani et al.[11] studied the impact of FFs on phytosociology, regeneration

pattern, biomass, fauna, etc. Thus, it is imperative to develop mitigation and adaptation measures to reduce/ overcome the adverse impacts of FFs.

Advances in satellite-based surveillance and GIS over the past three decades have made significant contributions in enhancing the understanding of the causes and impacts of FFs among researchers across the globe. Chuvieco and Congalton[12] integrated digitally processed moderate-resolution Landsat TM data with other layers of geographic information to derive a FF hazard map. White et al.[13] mapped the burn severity due to various topographic, vegetation and meteorological factors using optical satellite data. Review of the literature on active fire characteristics and post-fire impacts is available[14]. These patterns are detected and mapped using satellite data. Robinson[15] demonstrated the potential of infrared sensors with cloud-penetrating capabilities for mapping fire from space. Space-based inputs and GIS are also utilized for FF risk zonation[16,17] and simulation modelling[18]. Studies highlighting the factors responsible for FFs, viz. climate and anomalies in a past fire event is carried out using remote sensing/GIS to help understand the major causes[19]. Near real-time monitoring of FFs has been taken up by the National Remote Sensing Centre (NRSC) and Forest Survey of India (FSI) using MODIS sensor onboard Terra and Aqua satellites all over the country[20]. Recently Dubey et al.[21] proposed a more efficient FF detection system using IoT and artificial neural networks.

In spite of the demonstrated application of remote sensing and GIS technologies in FFs, the situation due to FFs in many regions of India, including the mountain state of Uttarakhand is gloomy. The ravaging FFs in the hills of Uttarakhand continue to occur every year during peak summer season, with reported increase in their frequency over the years[22]. It would not be wrong to say that the current knowledge and understanding of FFs is not sufficient for effective decision-making. There exist multiple legislative and administrative challenges in the implementation of actions on the ground. Strategic thinning, prescribed fire and managed wildfire are the most recommended solutions to the challenges faced in mitigating FFs across the globe[23]. However, these are labour-intensive tasks, whereas the Forest Departments and Revenue Departments are not equipped with sufficient human and financial resources. Thus, it becomes essential to involve local communities in mitigation measures, since villagers can serve as immediate fire fighters in the case of FFs. Community-based wildfire planning has become an important strategy in wildfire risk management to reduce risks and improve community capacity to wildfire management[24]. The role of VPs in mitigating FFs in Uttarakhand is also considered as a promising proposition[25]. However, there are instances where VPs have logjams with the Forest Department for being held responsible for the FFs.

The aim of the present study was to derive spatially explicit information representing the relationship between instances of FFs and location of VPs in Almora district, Uttarakhand. The results obtained would assist decision makers to identify the actual conflict areas of VPs and FFs. Such inputs are expected to be useful in any evidence-based decision making for mitigating FFs in Uttarakhand.

Study area

Almora is one of the 13 districts of Uttarakhand, located between 29°30′–30°20′N lat. and 79°20′–80°20′E long. in the Lesser Himalaya (Figure 1). The total geographical area of the district is 3365 sq. km. Administratively, the district comprises 9 tehsils, 11 developmental blocks and 2282 villages out of which 102 are uninhabited. It has 1146 Gram Panchayats (GPs) and 2199 VPs covering an area of 69,853.07 ha. The district displays large variations in altitude and relief, which to a great extent shapes the variation of vegetation from tropical moist deciduous forest to moist mixed coniferous forest. The climatic conditions also exhibit great variation in seasons across the year. In summer, May and June are the hottest months. During this period, the temperature rises from 12°C to 28°C and occurrences of FFs are common. In winter, January is the coldest month, when the minimum temperature goes down to 2°C or below. The rainy season is characterized by heavy rainfall – between 1500 and 2000 mm in summer and 500 and 700 mm in winter. The monsoon season begins in June, stays up to August receiving 90% of the total precipitation while November is the driest month. Winter rains are erratic.

Methodology

We used the Exploratory Spatial Data Analysis (ESDA) approach to study the relationship between VP locations and FF occurrences. Broadly defined as a collection of techniques to describe and visualize spatial distributions, identify atypical locations (spatial outliers), discover patterns of spatial association (spatial clusters), and suggest different spatial regimes and other forms of spatial instability or spatial non-stationary[26]. The overall motive is to use data in an inductive fashion to gain new insights about patterns and relationships within them, without necessarily having a firm, preconceived, theoretical notion[26]. We used interactive ESDA tools and functionalities that are available in the ArcGIS software ver. 10.6 for this study. The standard data of fire products of the moderate resolution imaging spectroradiometer (MODIS; MCD14DL) and Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m (VNP14IMGTDL_NRT) were downloaded from Archive Download tool of
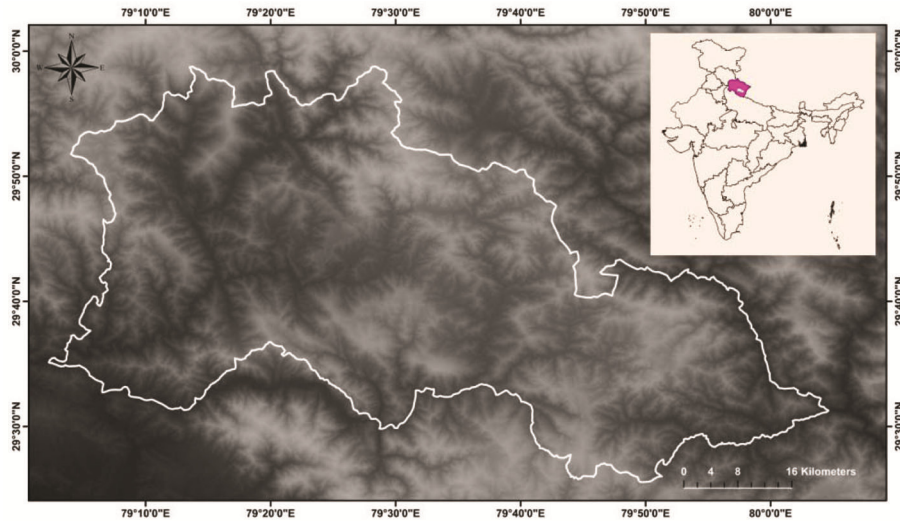
Figure 1. Location map of the study area (administrative boundary of Almora district, Uttarakhand, India, overlaid on the CartoSAT Digital Elevation Model, showing physiographical gradient in the region).
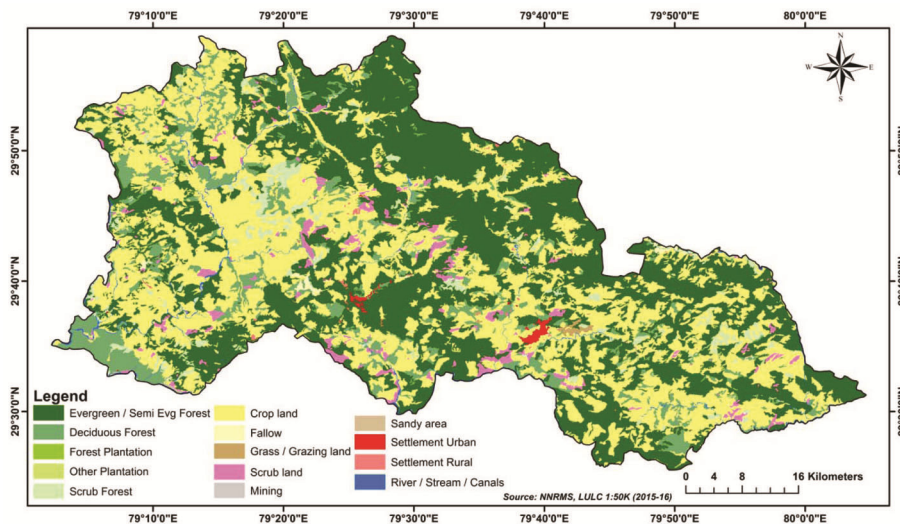

Figure 2. Land-use land-cover map of Almora District.

earthdata.nasa.gov e-fire-data for the current fire season, during February to June 2019. Detailed information on the location of VPs in terms of latitude–longitude and other attributes was downloaded from the Uttarakhand Forest Department website. A shape file was created in the geographical projection system after cleaning the data and further projected into UTM projection, Zone 44. A spatial grid of 1 km × 1 km was developed using fishnet command and the FF events and number of VPs in each grid were calculated using spatial join function This grid was further used to derive spatial clusters of high as well as low values of FFs and VPs using hot-spot analysis in spatial analysis tools to identify statistically significant spatial clusters of high value (hot spots) and low value (cold spots). Overlay analysis was performed on the hot-spot maps to identify areas of conflict of VPs with FFs,

and vice versa. Four categories indicating the spatial relationship between VPs and FFs were identified, viz. VPs cold spot–FFs cold spot; VPs cold spot–FFs hot spot; VPs hot spot–FFs cold spot and VPs hot spot–FFs hot spot. Towards the end, we performed zonal analysis of the overlay map with the National Natural Resource Management System (NNRMS) 1 : 50 K Land-Use Land-Cover data (LULC) (Figure 2), to derive further insights on the dominant LULC in each category and its contribution to FFs, if any.

Results

The major findings pertaining to spatial relationship between FFs and VPs are discussed below (Figure 3).
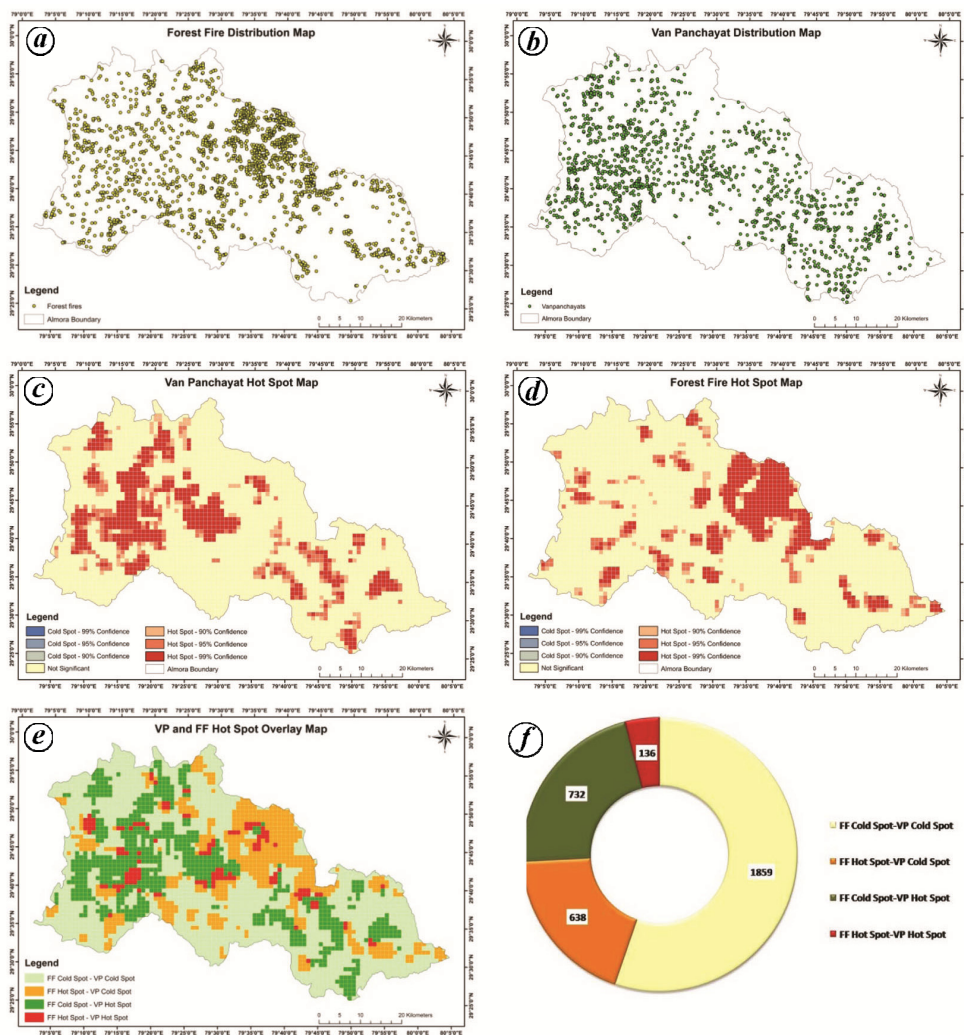
Figure 3. *a*, Spatial distribution of forest fire (FF) locations. *b*, Spatial distribution of van panchayats (VPs). *c*, VP hot spot map. *d*, FF hot spot map. *e*, Overlay map of FF and VP hot spots. *f*, Bubble graph of percentage area under different clusters.

VP cold spot–FF cold spot

These are the areas representing low clustering of both VPs and FFs. The total number of grids covered was found to be 1859 out of 3365 grids (Table 1). Covering almost half (55.24%) of the district, the major land use classes were found to be forest and crop land (Table 2). Twenty-five per cent of VPs mapped in the district were found to be in this category.

VP cold spot–FF hot spot

These are the areas with low clustering of VPs and high clustering of FFs events. The total number of grids in this class was found to be 638, representing 18.9% of the district. The total number of VPs in the cluster was only 152, i.e. 7.6%. Certainly, in these areas, FFs cannot be attributed to anthropogenic pressure due to lower percentage of VPs. Though determining the actual cause of a

fire is beyond the scope of this article, the favourable natural conditions that ignite a fire and further lead to its spread might be the major causative factor of FFs.

VP hot spot–FF cold spot

This category represents the areas with high clustering of VPs and low clustering of FFs, thus, indicating low occurrences of FFs in the highly clustered VPs. The total number of grids covered was found to be 732, representing 21.7% of the total geographical area of the district. This category was also found to have the highest number of VPs, i.e. 1128. The high clustering of VPs and low clustering of FFs in these grids indicate the active role of VPs in safeguarding the forests from fires. It also points towards the increased sense of awareness among the VPs. Probably, FFs in these areas might be due to the spread of fire from the crop land, which is the major land use class, followed by the evergreen/semi-evergreen forest.

Table 1. Summary of area coverage in forest fire (FF)–van panchayat (VP) clusters of hot-spot analysis in Almora District, Uttarakhand, India

Class	No. of grids (1 km × 1 km)	In %	No. of VPs
FFs cold spot–VPs cold spot	1859	55.24	533
FFs hot spot–VPs cold spot	638	18.9	152
FFs cold spot–VPs hot spot	732	21.7	1128
FFs hot spot–VPs hot spot	136	04.0	192
Total	3365	100	2005*

*Corrected coordinates were available for 2005 out of total 2199 VPs.

Table 2. Land-use class-wise summary of area (ha) under FF–VP clusters of hot-spot analysis in Almora district, Uttarakhand

Significance level	VPs cold spot and FFs cold spot	VPs cold spot and FFs hot spot	VPs hot spot and FFs cold spot	FFs hot spot and VPs hot spot	Total
Urban	493.14	12.33	302.05	0.00	807.52
Scrub forest	4,863.60	844.50	2,582.82	369.86	8,660.78
Grass/grazing land	246.57	221.91	12.33	0.00	480.81
Scrub land	4,518.40	980.12	1,738.32	228.08	7,464.91
Sandy area	104.79	12.33	0.00	0.00	117.12
Rural	277.39	86.30	258.90	6.16	628.75
River/stream/canals	1,645.86	283.56	702.72	129.45	2,761.59
Mining	6.16	0.00	0.00	0.00	6.16
Crop land	67,362.97	14,245.59	39,543.69	5,991.66	127,143.91
Plantation	43.15	61.64	24.66	30.82	160.27
Fallow	628.75	24.66	289.72	30.82	973.95
Evergreen/semi-evergreen forest	67,979.40	42,108.02	19,503.70	5,270.44	134,861.56
Deciduous forest	16,797.59	2,940.35	8,093.67	1,553.39	29,385.00
Total	164,967.77	61,821.31	73,052.58	13,610.67	313,452.33

VP hot spot–FF hot spot

This category is the most important, having high spatial clustering of VPs as well as, high clustering of FFs, which is a cause for concern. The total number of grids in this category was found to be 136, i.e. only 4% of the total geographical area of the district with the presence of only 192 VPs. Nevertheless, these are highly significant due to the fact that most massive fires occur when there are several cases of ignition over a wide area that quickly coalesce into a single fire, burning intensely over a large area[27]. The analysis of LULC vis-à-vis each cluster as described above was found to have variable contribution of different classes, most likely depending upon the existing management practices. However, crop land and evergreen/semi evergreen forest were found to be the dominant classes (Table 2).

Discussion

For the rural communities living in the mountains, forests are amongst the most dependable common property resources. Nevertheless, forest-related problems in the mountains are also diverse, complex and far-reaching. FFs are one among many such issues. In Uttarakhand, these fires are primarily considered to be anthropogenic in nature. Over the years, increase in average temperature and decrease in rainfall have also been cited as the reasons for increase in FFs. During the past 53 years, climatic data also show that the average temperature of Almora, i.e. 17.55°C (1955–2007) has increased up to 0.46°C and the district is now receiving 23% or 244 mm less annual rainfall compared to its 53 years annual average rainfall, i.e. 1060 mm (ref. 28).

Irrespective of what causes FFs, there is a need for an efficient system to mitigate the same, so that a continuous supply of ecosystem services emanating from forests is ensured for people in the mountains as well as those in the lowlands in a sustained manner. There is an urgent need for a robust fire management policy framework for the state. In such a framework, early attack is considered as the first step in suppressing a fire. However, without proper planning, policies, prevention, fuel management, community involvement and detection, the early attack might not be successful. In areas that are mapped under VP hot spots and FF hot spots, awareness and educational activities can be effective by involving the community and other groups in a fire management programme and engaging the community as a responsible partner[29]. This will not only arrest the fire in areas identified as hot spots, but will also help in preventing its spread in adjacent areas. It is here, that the role of VPs in mitigating FFs is further evident, as they are the first ones to help the administration and Forest Department in their efforts to suppress FFs. Thus, a greater role of stakeholders beyond ownership and deeper understanding of other contributing factors are identified as the necessary aspects to address future forest governance challenges[30]. In the areas mapped under VP hot spots and FF cold spots, it

is evident that VPs play a significant role in stewarding their forests from fires. Thus lessons can be learnt on the best practices and traditional knowledge gained by them in safeguarding the VP hot spot and FF hot spot clusters.

Conclusion

The solution to FFs cannot be envisaged/expected from either the Government machinery or the people independently. Aligning the objectives of FF management with the social set-up and needs of the FDCs will further improve their confidence, making the task easier and cost effective[31]. This study is a novel attempt to map the linkages of FFs and VPs in a spatially explicit manner into various categories, indicating the areas where VPs can be held responsible for promoting or arresting FFs using ESDA. Insights thus obtained may serve as crucial inputs for evidence-based decision-making that may be helpful in bridging the gaps in the existing knowledge of FFs in Uttarakhand.

1. Fisher, R. J., Srimongkontip, S. and Veer, C., People and forests in Asia and the Pacific: situation and prospects. In Asia-Pacific Forestry towards 2010. Asia-Pacific Forestry Sector Outlook Study Working Paper Series (Food and Agriculture Organization), 1997.
2. Chao, S., Forest people: numbers across the world. Forest Peoples' Program, Moreton-in-Marsh, UK, 2012.
3. Biswas, P. K., Forestry-based sustainable development: the social dimensions. *Indian J. Public Admin.*, 1993, **XXXIX**(3), 473–478.
4. Fisher, R. J., Collaborative management of forests for conservation and development. IUCN, Gland Switzerland, 1995, p. 65.
5. Arnold, J. M. and Stewart, W. C., Common property resource management in India. Oxford Forestry Institute, University of Oxford, UK, 1991.
6. Farooquee, N. A. and Maikhuri, R. K., Role of the state on forests: case of Uttarakhand. *Econ. Polit. Wkly*, 2007, 3537–3540.
7. MoEFCC, India State of Forest Report, Ministry of Environment, Forest and Climate Change, Government of India, 2005.
8. MoEFCC, India State of Forest Report, Ministry of Environment, Forest and Climate Change, Government of India, 2017.
9. Jha, C. S. *et al.*, Monitoring of forest fires from space-ISRO's initiative for near real-time monitoring of the recent forest fires in Uttarakhand, India. *Curr. Sci.*, 2016, **110**(11), 2057–2060.
10. Goldammer, J. G., History of equatorial vegetation fires and fire research in Southeast Asia before the 1997–98 episode: a reconstruction of creeping environmental changes. *Mitigat. Adapt. Strat. Global Change*, 2007, **12**(1), 13–32.
11. Kodandapani, N., Cochrane, M. A. and Sukumar, R., Forest fire regimes and their ecological effects in seasonally dry tropical ecosystems in the Western Ghats, India. In *Tropical Fire Ecology*, Springer, Berlin, Germany, 2009, pp. 335–354.
12. Chuvieco, E. and Congalton, R. G., Application of remote sensing and geographic information systems to forest fire hazard mapping. *Remote Sensing Environ.*, 1989, **29**(2), 147–159.
13. White, J. D., Ryan, K. C., Key, C. C. and Running, S. W., Remote sensing of forest fire severity and vegetation recovery. *Int. J. Wildland Fire*, 1996, **6**(3), 125–136.
14. Lentile, L. B. *et al.*, Remote sensing techniques to assess active fire characteristics and post-fire effects. *Int. J. Wildland Fire*, 2006, **15**(3), 319–345.
15. Robinson, J. M., Fire from space: global fire evaluation using infrared remote sensing. *Int. J. Remote Sensing*, 1991, **12**(1), 3–24.
16. Roy, P. S., Forest fire and degradation assessment using satellite remote sensing and geographic information system. In Satellite Remote Sensing and GIS Applications in Agricultural Meteorology (eds Sivakumar, M. V. K. *et al.*), Proceedings of the Training Workshop, 7–11 July 2003, Dehra Dun, India, 2003, p. 361.
17. Babu, K. S., Roy, A. and Prasad, P. R., Developing the static fire danger index using geospatial technology. In Second International Conference on Contemporary Computing and Informatics (IC3I), IEEE, Noida, India, December 2016, pp. 558–563.
18. Kanga, S. and Singh, S. K., Forest fire simulation modeling using remote sensing and GIS. *Int. J. Adv. Res. Comput. Sci.*, 2017, **8**(5), 326–332.
19. Kale, M. P. *et al.*, Are climate extremities changing forest fire regimes in India? An analysis using MODIS fire locations during 2003–2013 and gridded climate data of India meteorological department. *Proc. Natl. Acad. Sci., India Sect. A*, 2017, **87**(4), 827–843.
20. Reddy, C. S. *et al.*, Nationwide assessment of forest burnt area in India using Resourcesat-2 AWiFS data. *Curr. Sci.*, 2017, **112**, 1521–1532.
21. Dubey, V., Kumar, P. and Chauhan, N., Forest fire detection system using IoT and artificial neural network. In Proceedings of the International Conference on Innovative Computing and Communications, Springer, Singapore, 2019, pp. 323–337.
22. Gupta, S., Roy, A., Bhavsar, D., Kala, R., Singh, S. and Kumar, A. S., Forest fire burnt area assessment in the biodiversity rich regions using geospatial technology: Uttarakhand forest fire event 2016. *J. Indian Soc. Remote Sensing*, 2018, **46**(6), 945–955.
23. Jeronimo, S. M., Kane, V. R., Churchill, D. J., Lutz, J. A., North, M. P., Asner, G. P. and Franklin, J. F., Forest structure and pattern vary by climate and landform across active-fire landscapes in the montane Sierra Nevada. *For. Ecol. Manage.*, 2019, **437**, 70–86.
24. Brenkert-Smith, H., Building bridges to fight fire: the role of informal social interactions in six Colorado wildland–urban interface communities. *Int. J. Wildland Fire*, 2010, **19**(6), 689–697.
25. Dobriyal, M. and Bijalwan, A., Forest fire in western Himalayas of India: a review. *N. Y. Sci. J.*, 2017, **10**(6), 39–46.
26. Anselin, L. and Rey, S. J., Perspectives on spatial data analysis. In Perspectives on Spatial Data Analysis, Springer, Berlin, Heidelberg, 2010, pp. 1–20; https://pdfs.semanticscholar.org/a8ff/04baa-48d44ccd22851471dd4467f47f5b368.pdf
27. Countryman, C. M., *Mass Fires and Fire Behavior*. Pacific Southwest Forest and Range Experiment Station, Forest Service, US Department of Agriculture, Berkeley, CA, 1964, vol. 19.
28. Dobhal, R. (ed.), Uttarakhand: State of the Environment Report (SOER)-2012. Bishen Singh, Mahendra Pal Singh, Dehradun, 2012.
29. FAO, Fire management: voluntary guidelines. Principles and strategic actions. Fire Management Working Paper 17, Food and Agriculture Organization, Rome, 2006; www.fao.org/forestry/site/35853/en
30. Agrawal, A., Chhatre, A. and Hardin, R., Changing governance of the world's forests. *Science*, 2008, **320**(5882), 1460–1462.
31. Negi, B. S., Chauhan, D. S. and Todaria, N. P., Administrative and policy bottlenecks in effective management of van panchayats in Uttarakhand, India. *Law Environ. Dev. J.*, 2012, **8**, 141.