8. Gillis, M., Leckie, D. and Pick, R., Satellite imagery assists in the assessment of hail damage for salvage harvest. *For. Chron.*, 1990, **66**, 463–468.
9. Parker, M. D., Ratcliffe, I. C. and Henebry, G. M., The July 2003 Dakota hailswaths: creation, characteristics and possible impacts. *Mon. Weather Rev.*, 2005, **133**, 1241–1260.
10. Krishna, T. M., Ravikumar, G. and Krishnaveni, M., Remote sensing based agricultural drought assessment in Palar basin of Tamil Nadu state, India. *J. Indian Soc. Remote Sens.*, 2009, **37**, 9–20.
11. Dutta, S., Singh, S. K. and Panigrahy, S., Assessment of late blight induced diseased potato crops: a case study for West Bengal district using temporal AWiFS and MODIS data. *J. Indian Soc. Remote Sensing*, 2014, **42**, 353–361.
12. Bhushan, C., Srinidhi, A., Kumar, V., Singh and Geetika, Lived Anomaly: How to enable farmers in India cope with extreme weather events, 2015, Centre for Science and Environment, New Delhi.
13. Ray, S. S., Neetu, Mamatha, S. and Gupta, S., Use of remote sensing in crop forecasting and assessment of impact of natural disasters: Operational approaches in India. FAO Expert Meeting on Crop Monitoring for Improved Food Security, Vientiane, Lao PDR; 02/2014, 2014.
14. Peters, A. J., Griffin, S. C., Viña, A. and Ji, L., Use of remotely sensed data for assessing crop hail damage. *Photo. Eng. Rem. Sens.*, 2000, **66**, 1349–1356.
15. Parihar, J. S. and Oza, M. P., FASAL: an integrated approach for crop assessment and production forecasting. Proc. SPIE 6411, Agriculture and Hydrology Applications of Remote Sensing, 641101 (11 December 2006); doi: 10.1117/12.713157.
16. Tripathy, R., Chaudhari, K. N., Mukherjee, J., Ray, S. S., Patel, N., Panigrahy, S. and Parihar, J. S., Forecasting wheat yield in Punjab State of India by combining crop simulation model wofost and remotely sensed inputs. *Remote Sens. Lett.*, 2013, **4**, 19–28.
17. Singh, R. S., Patel, C., Yadav, M. K. and Singh, K. K., Yield forecasting of rice and wheat crops for eastern Uttar Pradesh. *J. Agrometeorol.*, 2014, **16**, 199–202.
18. Singh, P. K. *et al.*, Rice (*Oryza sativa* L.) yield gap using the CERES-rice model of climatevariability for different agroclimatic zones of India. *Curr. Sci.*, 2016, **110**, 405–413.
19. Zhao, J., Zhang, D., Luo, J., Huang, S., Dong, Y. and Huang, W., Detection and mapping of hail damage to corn using domestic remotely sensed data in China. *Aus. J. Crop Sci.*, 2012, **6**, 101–108.
20. Molthan, A. L., Burks, J. E., Mcgrath, K. M. and Lafontaine, F. J., Multi-sensor examination of hail damage swaths for near real-time applications and assessment. *J. Ope. Meteor.*, 2013, **1**, 144–156.
21. de Leeuw, J. *et al.*, The potential and uptake of remote sensing in insurance: a review. *Remote Sens.*, 2014, **6**, 10888–10912.

ACKNOWLEDGEMENTS. We thank the Secretary, Department of Agriculture, Cooperation & Farmers' Welfare and Jt Secretary (IT), for their encouragement. We also thank the team members of FASAL project for providing the wheat crop map.

Received 18 September 2016; revised accepted 28 December 2016

doi: 10.18520/cs/v112/i10/2095-2100

Vulnerability of Indian Central Himalayan forests to fire in a warming climate and a participatory preparedness approach based on modern tools

Subrat Sharma* and Harshit Pant

G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora 263 643, India

Wildfires have been considered as part of the natural cycle, but the globe is witnessing them more often outside the natural cycle. In recent years, incidences of wild fire/forest fire are increasing globally, and also in India. The Himalayan region is not an exception, where wide inter-annual fluctuations occur in fire events, and a few of them lead to disasters resulting in immediate and cascading social and economic impacts and thus to vulnerability and exposure of Himalayan forests to current climate variability. Mountainous topography and insufficient state resources are a bottleneck to respond to fire disasters. This study analyses the role of climate as a precursor to large-scale forest fires, and the perception of village forest councils on the impact of forest fire and climate change. A framework has been proposed for integration of ground-based observation network and prevailing modern technologies as a mechanism to develop a fire potential index to reduce disturbances and for resource optimization in case of disastrous fires.

Keywords: Climate change, community forest, fire potential index, forest fire, Himalaya.

FOR the countries of the world, impacts of climate change are consistent with a significant lack of preparedness for current climate variability[1]. A changing climate leads to changes in the attributes of extreme events (frequency, intensity, spatial extent, duration and timing); hence unprecedented extreme weather and climate events are becoming frequent[2,3]. Impacts from recent climate-related extremes (heat waves, droughts, floods, cyclones, wildfires, etc.) reveal significant vulnerability to current climate variability (very high confidence)[2] and exposure to ecosystems[4], including many human systems. Global records from 1880 indicate a steady increase in warm years and increasing frequency[5], particularly after 1980 (Figure 1 *a*). This is also evident by the occurrence of ten warm years during the past decade (2001–10) and the warmest year (among all the previous years) till date[6], i.e. 2015. The same holds true for the Asian continent, where deficit in annual precipitation during the southwest monsoon season in India was also observed for the same year

*For correspondence. (e-mail: subrats@rediffmail.com)

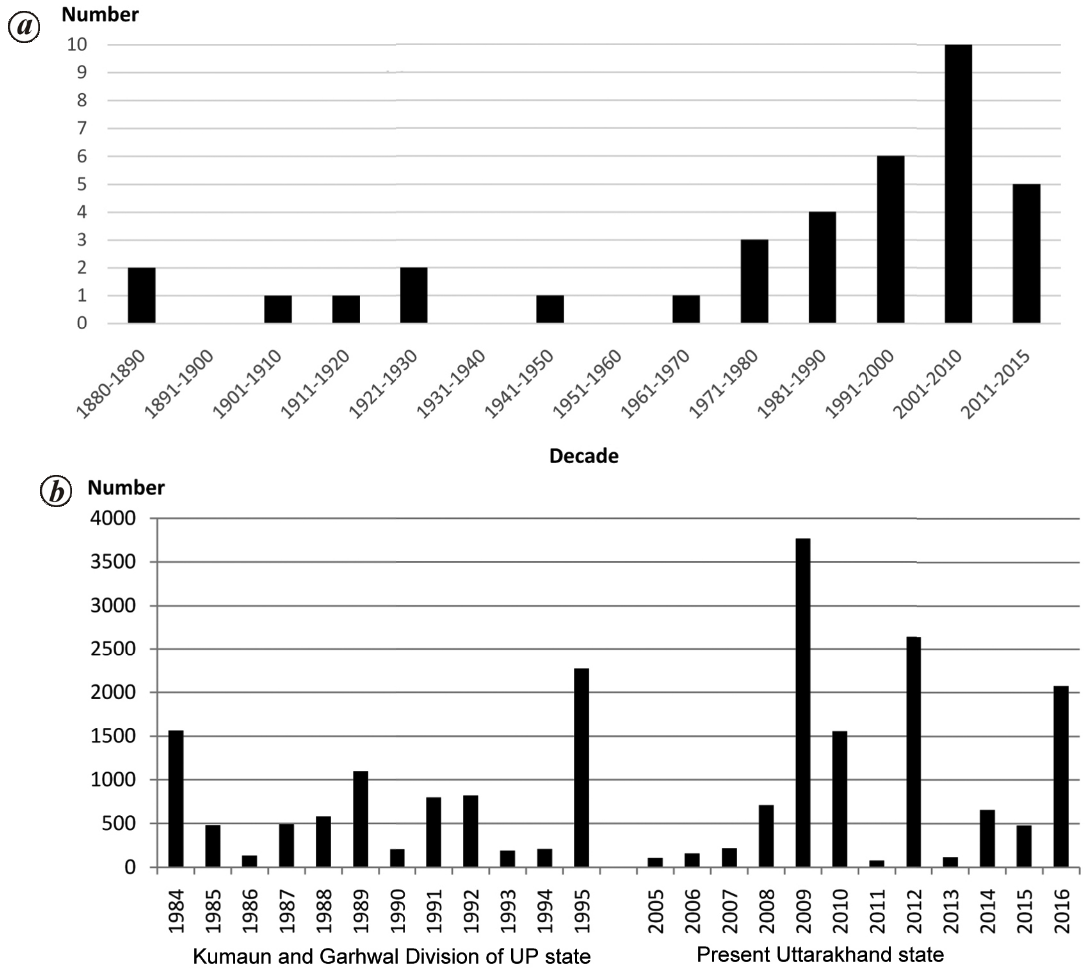

Figure 1. ***a***, Frequency of warm years in different decades. ***b***, Incidences of forest fire during some years before and after the creation of Uttarakhand state.

(2015)[7]. In 2015, rainfall during monsoon period (1 June to 30 September) was 86% of a large average of 50 years (1951–2000)[5]. In tune with the continental pattern, only half of the landscape in India received normal rainfall, while the other parts had deficient rainfall (23%–47% in different parts of the country)[7].

High temperature and less rainfall affect various ecosystem processes; thus over the past half a century climate change has affected many aspects of forest ecosystems, including tree growth and dieback, insect outbreaks, species distribution and seasonality of ecosystem processes[8]. About 39% of area in the monsoonal states of the northwestern Himalayan region (Himachal Pradesh and Uttarakhand) is under forest cover (India State of Forest Report 2015). These states received less rainfall in the warmest year of 2015 (deficient of 23% and 28% from the normal rainfall respectively)[7]. These attributes (continuous warm and dry periods) coinciding with leaf-fall period (ranging between February and May) in major tree species of the Himalayan forests[9], and followed by dry weather of the summer season, play a pivotal role in developing a high wildfire/forest fire potential in this part of the Himalaya[10,11]. These extreme climatic events may influence the extent of wildfire, its severity and frequency[11,12], and may be converted into disastrous events (Figure 1 *b*) on combining with other factors, e.g. management practices and governance issues. This is also apparent by the number of forest fire incidences occurring outside the administrative boundaries of the Forest Department of Uttarakhand in recent years[13]. Technological advancement has enabled to detect forest fires over a large landscape[12]; however, its efficacy remains in question in detecting small fires of short duration, particularly from dense forests[11]. The present study explores (i) the role of climatic variables as a precursor to forest fire, and (ii) suggests an 'early warning system' for preparedness or real-time reporting by integrating modern techniques (using commonly available tools) and people's knowledge on the ground (perceptions and observations on changes in local environment).

As the altitude and geology vary considerably, so do the vegetation types in Uttarakhand. Altitude ranges from nearly ~300 to above 6000 m amsl in the state. Large pattern of altitudinal occurrence of forests in Uttarakhand is as follows – on the lower slopes of the Siwalik ranges and foothills, forests dominated by *Shorea robusta* (sal) occur which are replaced by forests of *Pinus roxburghi* (chir-pine) above 1000 m. Chir-pine forests are preponderant in most of the Lesser Himalayan belt up to 1800 m, which is also the principal habitat zone of human settelment. Above the pine forests various species of oak (*Quercus*) dominate the higher elevations up to 3000 m (*Q. leucotrichophora*, *Q. floribunda* and *Q. semecarpifolia*). High-altitude forests include *Abies pindrow*, *Betula utilis*, *Aesculus indiac*, *Juglans regia*, etc.).

Daily reports of fire incidence were obtained from the State Forest Department[13] and analysed for distribution over a temporal scale (total of weekly incidences). The Forest Department recruits fire watchers and makes arrangements on the ground to report and control forest fires; however, the terrain and limited resources make it impossible to reach everywhere in the mountainous topography of the state (Figure 2).

In 2015, nearly 20% of the fire incidences occurred in the areas outside the Reserve Forests (i.e. Civil Soyam/ Community Forest or Van Panchayat), which increased considerably in 2016 (35% of total fire incidences by June)[13]. Van Panchayat is managed by local villagers through a management council for each village forest (Chairman and Council Members). Fifteen Van Panchayat areas were identified and visited during the fire season of 2016 in the districts of Pauri (usually having the highest forest fire incidences among all the districts; source: forest statistics) and Rudraprayag to understand the perception of people who are directly linked with the management of these community forests, and are the prime stakeholder for the needs. Method for perception study includes informal discussions and structured questionnaires regarding observations on climate change and associated impacts that can be easily understood by the

Figure 2. High-intensity forest fire in a pine forest.

common man. These include general observations/ experiences on (i) awareness about the issue of climate change, (ii) important observations on changes in local weather (mainly temperature and precipitation), and occurrence of disasters, if any, and (iii) likely local indicators (responses of trees and crops, etc.) of climate change. Meteorological observations at a mid-Himalayan location, viz. Almora district were obtained from automatic weather station installed at the GB Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal. For developing integrated framework, analysis was done on the existing mechanism for strengths and weaknesses of the system on real-time monitoring and preparedness as an advance warning system.

The landscape of the Indian Central Himalaya (presently Uttarakhand and previously Kumaun and Garhwal divisions of the state of Uttar Pradesh) has an history of occurrence of forest fires[14]. Prolonged drought has been associated with forest fires of the last century (1921, 1930, 1942, 1970 and 1995)[15]. However, 2015 was globally the warmest and driest during post-monsoon period; it carried the dryness till the fall of summer of the next year, i.e. 2016 (Figure 3), which increased potential circumstances for forest fire occurrence, and eventually converted into fire disaster of 2016. With a continuous increase in air temperature from late January 2016 and no/minimal rainfall since October 2015, incidences of fire in the State started from February and March of 2016 (Figure 3); however, it was minimal (five in February, and 19 in March)[13]. With rising temperature without precipitation, fire incidences increased sharply in the following months of the summer season (April – 1057 in number and May – 979), where fresh leaf litter was accumulating on the forest floor, and was drying quickly in this environment, thus adding to increase in the fire potential for surface fire in these forests (Figure 2). Hence in 2016, 4433 ha of forests was affected by fire, of which 64% was in government forests. On an average more than 2 ha of forest area was affected during each fire incidence. This excludes 103 ha of plantation areas affected by fire in the state in the same year. A total loss of Rs 4.6 million was estimated due to forest fires during 2016 (ref. 13).

Dry weather spell also led to delayed ripening of fruits in the forests (e.g. *Myrica esculenta* which contributes significantly to local economy, and *Berberis asiatica*; as observed by the villagers). Forest fire incidences caused mortality of tree seedlings and saplings in the forests, which will affect regeneration in the long run. The unripe fruits on trees along with the dried ones indicate that the increasing temperature has affected the growth vigour, eventually leading to either mortality or late ripening. Before the fire season, edible forest fruits became dry either or did not ripen which resulted in delayed marketing and thus affected the livelihood (e.g. *M. esculenta*), but

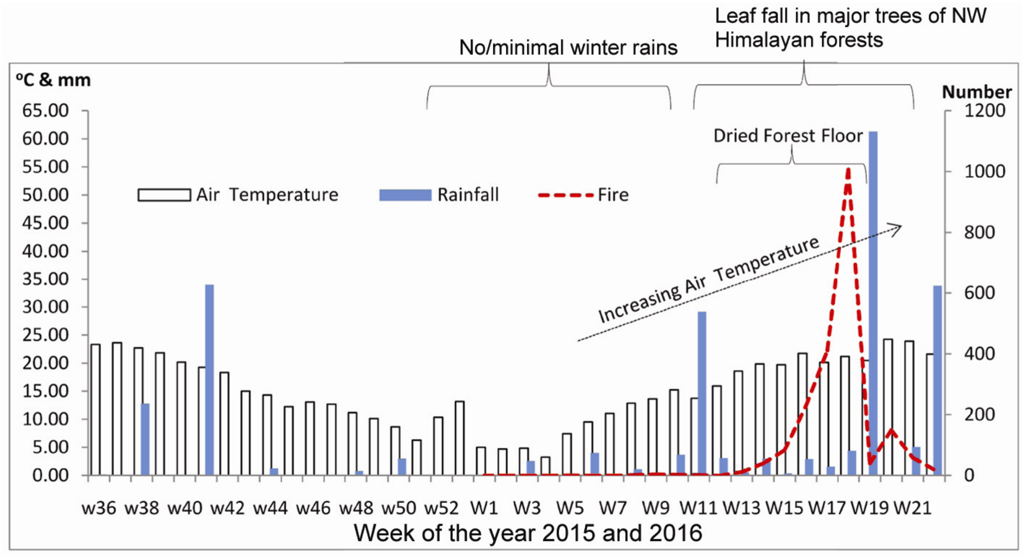

Figure 3. Weekly climate in the preceding year (2015), and early season at mid-Himalayan location (Kosi-Katarmal), and total fire incidences of 2016 in Uttarakhand. Gaps in January and February 2016 are due to missing data for those weeks.

Table 1. Observations/experiences of villagers and impacts felt during and after major forest fires

Observation/experience	Visible impact felt/experienced
Smoke and particles in air	Decline in visibility Breathing problem
Falling of stones after forest burning on the road and habitation below	Threat for human life on the road and livestock in the villages located below Damage to property – car, bus, etc.
Dead vegetation due to burning of forest floor	No revival of saplings and seedlings due to mortality Fodder not available due to complete damage of plants, even in the next year
Falling of burning cones of pine or burnt logs	Spread of forest fire in down slope

after a fire event, there is wide-scale loss of such livelihood options and forest vegetation.

General observations of Van Panchayat managers were as follows: (i) awareness about the issue of climate change (100% respondents); (ii) changes in the local weather of a particular area (100%), and (iii) increase in forest fire in recent years (100%), which is also apparent from the records of the Forest Department (Figure 1 *b*). Majority of them (66.6%) were either not able to associate other natural disasters with climate change or did not have any opinion regarding the issue. Most of them (86.7%) were of the opinion that generally air temperature has increased in the last three decades; however the remaining (13.3%) were not sure about it. Similarly, most of the respondents (87%) observed a reduced length of winter season; however, 13% mentioned that it has increased. Among the snowfall receiving locations in this study people did not notice any changes in the amount of snowfall received (66.7%), however 13% of respondents were not observant on this (Don't Know category). Prevailing general agreement among the respondents was on the pattern and quantum of precipitation (duration of rainy season and amount of rainfall), and increased intensity of rainfall (100% respondents for all three parameters). High-intensity rainfall for short duration is frequent in recent years, and a few of them are converted to cloud burst leading to a disaster. Immediate experiences/observations during and post-fire disaster are impacts on health, danger to life, loss of property, and negative changes in the surrounding environment and forest ecosystem (Table 1).

Perceived changes of Van Panchayat managers regarding local weather and climate are in agreement with the experiences of a large section of society across the state and observed evidences from the state[16]. Thus an aware person/villager in a remote locality may act as a vigilant eye on the ground, and can provide crucial inputs to a dedicated centrally located 'Fire Information and Control System' of the state. Uttarakhand has more than 12,000 community forests spread all across the 13 districts in varied topography. Thus, it can be converted into a huge ground-based network of people (village councils) with

Table 2. Inputs from the ground network to develop 'forest fire potential index'

Input	Likely impact on forest fire (+) (high), (–) low
Ground-based condition of forest floor	
Thick layer of dried leaves	+
Dryness of litter	+
Heavy leaf fall	+
Weather (last seven days) at a locality of Van Panchayat/range/compartment	
Rain showers	–
Sunny days	+
Human activities (chances of accidental fires)	
Movement of grazers	+
Movement of tourists	+

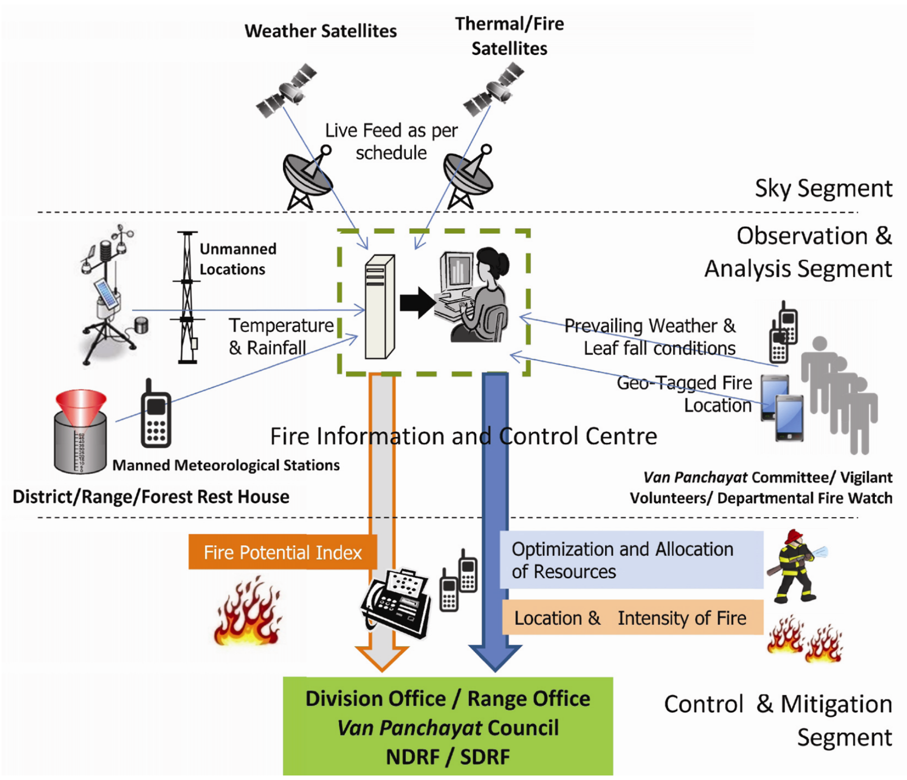

Figure 4. Framework for integration of ground observations and modern technologies to reduce forest fire risk.

the aid of their mobile phones. These mobile phones (simple ones) should have geo-referencing at the time of registration, so that locations are easily understood and plotted on geo-spatial domain using GIS, i.e. 'registered mobile phones'. For smartphones, a simple application (App) may be developed for receiving fire-related information and other observations from different localities submitted by various people (Table 2). Such Apps have an advantage of receiving information in different forms, i.e. text and photographs that can be tagged in real time for geo-referencing. Thus flow of information from different ground locations will be helpful in developing a 'fire potential index'. This can be drawn on inputs received from various localities – (i) prevailing ground conditions, i.e. local weather (rainfall – occurrence of rain showers, and temperature – warm conditions in the past few days or weeks), (ii) leaf fall intensity in nearby forest tree species, and status of leaf litter (dry, semi-dry or wet), particularly in the areas of preponderance of chir-pine trees which have highly inflammable leaf litter that coincides with dry summer[9], (iii) real-time weather report from meteorological satellites (probability of rainfall in near the future), and (iv) spotting of active fire (MODIS/SNPP-VIIRS). Such an index or alert with geo-spatial coordinates (in terms of compartment/beat/range or names of Van Panchayat) can be broadcast (short message service and App developed for this purpose).

The ground-based vigilant citizens/councillors/forest field staff can also act as additional 'field watchers' in providing first-hand information on the occurred and intensity of forest fires in their surrounding localities. Integration of fire potential index with inflowing information from different localities will play a vital role to allocate resources for firefighting, which may be optimized through a decision support system on GIS (Figure 4). Such preparedness is a pre-requisite to combat threats of climate change (extreme event in this case) when coupled with responses of the natural system (unsynchronized leaf fall in trees) and anthropogenic activities (poor governance, accidental fire, limited resources, etc.).

More than half of the forest cover of India is subjected to fires each year, and beside the consequences on structure and functioning of the ecosystem, may cause a huge economic loss (over Rs 440 crores)[12]. Causes of forest fire are attributed to various natural and anthropogenic (deliberate and accidental) factors[17]. Man and forest are interspersed in the Himalayan landscape, and till date historical linkages with surrounding forest exist. Forests of the Indian Central Himalayan region (Uttarakhand) are well documented to provide vital support for sustenance of village functioning[18,19]. This region has a history (since colonial period) to oppose the State Forest Management, if restrictions are imposed. In such cases resentment was shown by burning those forests which were controlled by the Forest Department[14]. Declaring 'forest crime' with imprisonment and a heavy fine had made the State Forest Management unpopular. Forest fires of 1921, 1930 and 1942 are being associated with people's movement for rights in the forest and for independence[15]. However, the same land has also witnessed the famous forest conservation movement, 'Chipko' by villagers to protect their forests. Thus, this Himalayan landscape has the potential for weaving social values into forest management and its protection. Existing management structure of community forests (~12,000 forest councils in Uttarakhand) may be activated through incentive-based mechanism, and may be combined during the active fire season with locally deployed resources of the Forest Department. Use of modern techniques (ground to sky) are key features in combating forest fires and also to scale down the social, economical, and ecological consequences and adverse effects. Community forest councils and aware villagers/citizens are important in the preparedness (fire potential index) and management of forest fire (during the event) to conserve valuable forest wealth of the Himalaya. The proposed integrated approach will reduce the vulnerability of Himalayan forests to impacts of climate change in the mountains and elsewhere.

1. IPCC, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (eds Field, C. B. *et al.*), Cambridge University Press, Cambridge, UK, 2012, p. 582.
2. IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds Field, C. B. *et al.*), Cambridge University Press, Cambridge, UK, 2014, p. 1132.
3. IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds Barros, V. R. *et al.*), Cambridge University Press, Cambridge, UK, 2014, p. 688.
4. Easterling, D. R., Meehl, G. A., Parmesan, C., Changnon, S. A., Karl, T. R. and Mearns, L. O., Climate extremes: observations, modeling, and impacts. *Science*, 2000. **289**, 2068–2074.
5. GISTEMP Team, GISS surface temperature analysis (GISTEMP). NASA Goddard Institute for Space Studies, 2016; http://data.giss.nasa.gov/gistemp/ (accessed on 28 July 2016).
6. World Meteorological Organization, 2016; http://public.wmo.int/en/media/press-release/2015-hottest-year-record
7. India Meteorological Department, 2015; http://hydro.imd.gov.in/hydrometweb/(S(norlim2djvelo1yhkcyuzt55))/Rainfallmaps.aspx (accessed on 28 July 2016).
8. Seppälä, R. Buck, A. and Katila. P. (eds), Adaptation of Forests and People to Climate Change. A Global Assessment Report, IUFRO World Series Volume 22, Helsinki, 2009, p. 224.
9. Negi, G. C. S., Phenology and nutrient dynamics of tree leaves in Kumaun Himalayan forests. Ph D thesis, Kumaun University, Naini Tal, 1989.
10. Sharma, S. and Rikhari, H. C., Forest fire in the Central Himalaya: climate and recovery of trees. *Int. J. Biometeorol.*, 1997, **40**, 63–70.
11. Singh, R. D., Gumber, S., Tewari, P. and Singh, S. P., Nature of forest fires in Uttarakhand: frequency, size and seasonal patterns in relation to pre-monsoonal environment. *Curr. Sci.*, 2016, **111**(2), 398–403.
12. 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.
13. State Forest Department, 2016; http://www.vigilanceandlegalcell.co.in/fire/Office-Fire.html (accessed on 28 July 2016).
14. Guha, R. and Gadgil, M., State forestry and social conflict in British India. *Past Present*, 1989, **123**, 141–177.
15. Mehta, J. S., Forest fires and land degradation in Uttarakhand. In *Land Utilization in Central Himalaya: Problem and Management Options* (eds Kumar, K., Dhyani, P. P. and Palni, L. M. S.), Indus Publishing Company, New Delhi, 1996, pp. 125–133.
16. Rautela, P. and Karki, B., Impact of climate change on life and livelihood of indigenous people on Higher Himalaya in Uttarakhand, India. *Am. J. Environ. Prot.*, 2015, **3**(4), 112–124.
17. Satendra and Kaushik, A. D., Forest fire disaster management. National Institute of Disaster Management, Ministry of Home Affairs, Government of India, 2014, p. 279.
18. Singh, J. S., Pandey, U. and Tiwari, A. K., Man and forests: a central Himalayan case study. *AMBIO*, 1984, **13**(2), 80–87.
19. Sharma, S. and Singh, S. P., Energy use pattern and sustainable development: a case study in rural landscape of the Central Himalaya. *Landsc. Urban Plan.*, 1994, **29**(1), 19–24.

ACKNOWLEDGEMENTS. We thank the Director, GBPNIHESD, Almora for providing the necessary facilities for this study and Dr Sandipan Mukherjee for providing meteorological data.

Received 24 August 2016; revised accepted 2 December 2016

doi: 10.18520/cs/v112/i10/2100-2105