Citizen-centric tool for near real-time mapping of active forest fires

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In this study, a mobile app is presented as a citizen-centric geospatial solution to record real-time forest fire incidents. This tool fetches accurate geographical coordinates and captures forest fire images, along with relevant fields related to the event such as cause of fire, fire type, species affected, etc. in both online and offline mode. The background, application foundation, system design and main features are also described. Evaluation of robustness of the application and a case study are presented to show the potential use of this participatory sensing-based geospatial tool.

Keywords: Citizen science, forest fire, geospatial tool, mobile application, real-time mapping.

FORESTS are the source of a variety of goods and services, and play a key role in maintaining environmental balance. Forest fires are a common feature in about 55% of the forest area in India. The forests in our country are degrading at an alarming rate due to fire incidents. In recent decades, increased incidences of forest fire are being witnessed from different parts of India[1]. The Himalayan states, particularly Uttarakhand and Himachal Pradesh have witnessed several episodic forest fire events during summer seasons in recent years. The forests of Western Himalaya are more susceptible to fires due to expansion of resin-containing pine (chir) forests that catch fire easily. Likewise, states in the Northeast have also experienced increasing incidences of forest fires due to intensive shifting cultivation and uncontrolled burning[2].

Owing to the variety of forest fires in India, both man-made and natural, it is challenging to collect information on such incidences in a timely and coordinated manner to update the authorities about the prevailing situation. For example, forest fire incidents may be caused due to natural calamities (unplanned burning), intentional human activities (planned burning of forests for farmlands) or accidental human activities[3]. Forest fires in NE India largely occur due to slash and burn agriculture practice. According to a recent report of the Forest Survey of India (FSI), 7.49% of forests in the country are exposed to moderately frequent fires, 54.40% to occasional fires and 2.40% to high fire levels, while 35.71% of India's forests have not been exposed to any kind of wildfires[4].

Although monitoring of active forest fires is being done through satellites (e.g. MODIS, VIIRS), owing to the limitation of spatial and temporal resolution several small-scale incidences of forest fires get missed. In such a scenario, smart mobile devices with a forest fire app can be handy for the field staff to record and report forest fire incidences in real-time to facilitate verification of a satellite-based active fire observation, report incidences which are missed by satellites and ascertain causes of such incidences.

In this article, a forest fire reporting mobile app is presented as a citizen-centric geospatial solution aimed to report forest fires by forest personnel. The app utilizes the citizen science approach for real-time forest fire reporting.

Citizen science

The rise of science with the slogan 'science for the people' was adopted in the 1970s, which has drastically changed in the 21st century to 'science by the people'. This clearly indicates that science is now available to all potential contributors as an activity and is not limited to just a few privileged people. This practice of engaging millions of trained or untrained individuals in a scientific endeavour through several research projects to collect, categorize, transcribe and analyse scientific data is known as citizen science[5]. The potential participants are known as citizen scientists, who make scientific contribution based on their observation skills which hold more relevancy than any expensive equipment[6].

Figure 1 highlights citizen sciences significant growth in the last few years. The factors responsible for such exponential growth of citizen science are[7]: (i) emergence of technical resources such as the internet and mobile computing to disseminate information related to projects and collect data from the public; (ii) increasing public–professional partnership leading to free labour, skill, cost and computation, and (iii) outreaching

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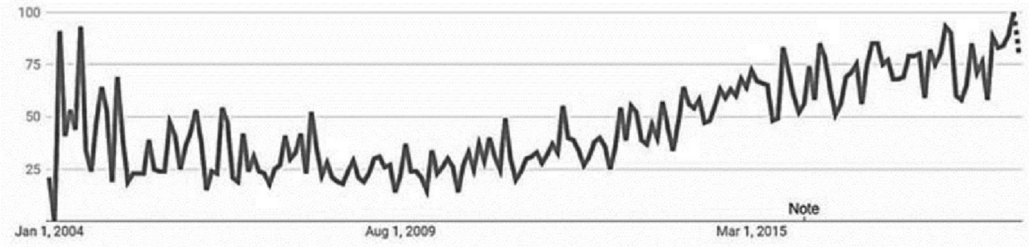

Figure 1. Google trend analytics of the term 'citizen science'.

in terms of public accountability by funding of projects so that people appreciate the importance of what they are paying for.

Levels of citizen science

Based on the idea of democratization, citizen science offers a different level of participation using the skill set and engagement of participants[8]. The spectrum of citizen science level is classified based on democratization as both include participation, right of decision-making, access to resources, support for individuals and groups, opportunities and equality, etc.[9]. The framework involves four levels of participation and engagement in a citizen science activity. The most basic level is 'crowd sourcing' which is defined as 'participation is limited to the provision of resources, and the cognitive engagement is minimal' and is not limited to only one group[10].

The second level is 'distributed intelligence', where participants are asked to undertake training and their cognitive ability is used as a resource. This training session indicates the quality of scientific work being carried out by the participants and awareness of the outsourced questions. The third level is 'participatory science', also known as community science, where problems are defined by the participants, and solutions are derived in consultation with scientists and experts as a method of data collection. Those groups of participants are not involved deeply in analysing the results; so this activity requires the assistance of experts to analyse and interpret the collected data and results.

The fourth level is 'extreme citizen science' (ExCiteS), where both professionals and non-professionals play equal roles such as decision-making regarding scientific problems, valid data collection to meet the scientific protocols, freedom to choose their level of engagement, and are involved in the analysis and publication of results.

This typology of citizen science participation facilitates the various groups of users to take part in scientific activities based on their potential and knowledge; for example, participants with expertise can discuss the results with scientists and suggest new ways of research. Thus, citizen science combined with the advancement in information technology (IT) increases the production and dissemination of knowledge in various research disciplines[11].

This article proposes a trans-disciplinary combined approach of citizen science and IT which will help forest officials in preventing or minimizing forest fire activities, and a messaging system that will help them in taking proper action when a fire breaks out[12].

Citizen science contribution to forest fire

The earlier work of citizen science regarding forest fire has addressed the use of geospatial solutions to map real-time incidents and generate map mashups for visualization and analysis purposes.

One of the most massive forest fires reported on 11 June 2003, in the north of the Colorado Springs, USA has been designated as the Black Forest Fire, in which 486 homes were destroyed and 14,000 acres of land was consumed by flames. This devastating incident resulted in US$ 420 million and towards insurance claims and US$ 3 million for firefighting costs[13]. This incidence is the best example of crowdsourcing activity, where participants provided the necessary resources and assistance to the disaster-prone areas.

Another example of citizen science application in a forest fire is the FD without fire system which uses crowdsourcing information as a base to generate alert reports, develop awareness regarding the situation for a better decision-making process and allocation of resources in an emergency[14].

However, the citizen science approach has opened up opportunities in identifying and mapping many other disasters[15–18], with forest fire being no exception. Cuff *et al.*[19] have highlighted the range of citizen science applications, and the collected data have been used for growth prediction and provided several new research directions.

Active forest fire monitoring challenges

Detecting active forest fires through satellites is an operational activity, yet it is difficult to locate the surface fires

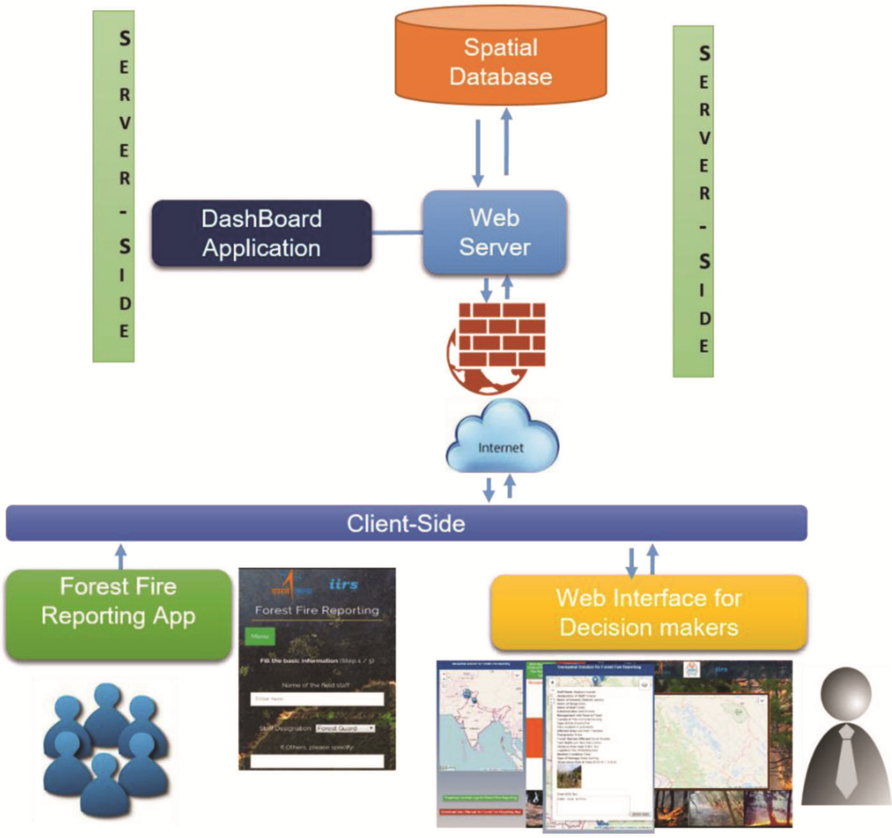

Figure 2. System architecture of the geospatial solution for forest fires.

under tall and dense forest canopies; fires occurring in narrow gorges also get obscured from the satellite view in mountainous terrain. Incidences of forest fire are common during the evening hours, and are always missed due to no overpass of active forest fire monitoring satellites. The VIIRS Suomi National Polar-orbiting Partnership (S-NPP) observation times are 1 : 30 pm and 1 : 30 am, whereas the orbiting of MODIS Terra is timed in the morning and Aqua in the afternoon. Also, the possibility of recognizing false fire pixels might be caused due to different illuminating conditions depending on weather and time variations. As a routine practice, the Forest Department carries out control fires to burn accumulating fuel load from time to time to minimize risk of large-scale forest fires. Information about such control fires and those caused by the people needs to be separated in space and time for better management. It is also challenging to ascertain the number of fire events that have occurred in any particular area from satellites, as these may provide several active fire alerts for a single event of fire depending upon its duration at a particular location. Also, due to coarse resolution of current satellites, many small-scale incidences of forest fire are missed. Finally, the post-fire damage and recovery assessment requires more detailed information on the fire-affected areas (e.g. forest beat), for which close-range observations of the fire-affected surfaces are necessary. All the above-mentioned issues can be resolved to a large extent by developing a forest fire management-oriented mobile app for geotagging of fires by the Forest Department personnel.

Methodology

Accurate information in real time is required for a quick response and rescue operation which can save human and animal lives from further disasters. Therefore, the geospatial solution proposed here is based on a participatory citizen science approach to map forest fire risk zones by geotagging and time tagging of fire incidents through a mobile device, and a web dashboard to visualize such incidents. Due to recent advancements in information and communication technology, geospatial mapping using mobile devices is changing the manner of real-time data collection with flexibility in data acquisition, data integrity and accuracy[20–24]. The use of mobile technology, embedded with GPS, camera, microphone and accelerometer, computation power, network connectivity and data plans has widened the engagement and participation at local, regional, national and international level.

Here, a mobile app and dashboard have been designed and developed to report forest fire incidents using the system architecture (Figure 2). The proposed geospatial solution follows the participatory science approach,

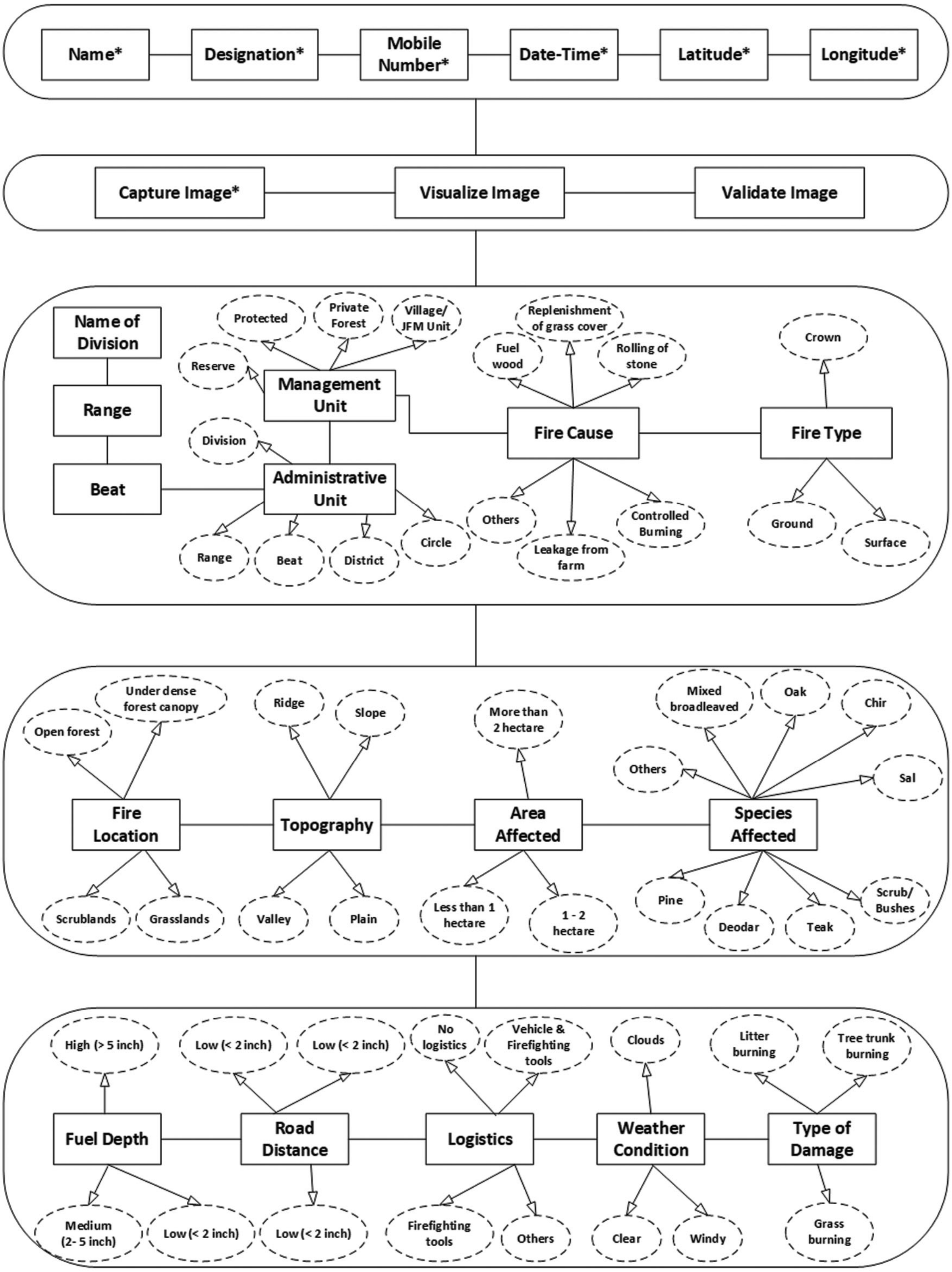

Figure 3. Components of Forest Fire Reporting mobile app.

where participants have relevant knowledge regarding scientific processes and activities and can use such information for better decision-making platforms[25].

According to Burke *et al*.[26] 'participatory sensing begins and ends with people, both as individuals and members of communities. The type of information collected, how it is organized, and how it is ultimately used, may be determined traditionally by a centrally organized body, or in a deliberative manner by the collection of participants themselves.'

Forest Fire Reporting mobile app (client-side application)

The Forest Fire reporting (FFR) mobile app (Figure 5) is a participatory sensing-based smartphone application that is specifically designed and developed in consultation with the participants' objectives and their goals to tackle forest fire incidents at the preliminary stage. Using this mobile app, geotagging of incident-prone sites is possible. Users can also record (photograph) the incident, fill basic fields relevant to the fire, and send all the collected information to a web application server (Figure 3). This mobile app is not only designed as a reporting tool for its users, but also as a means to visualize tagging patterns for monitoring sites, to make it transparent to the users as much as possible. Besides, this application includes a feature of offline storage when the network (or data) is not available.

The FFR mobile application was originally designed and developed using HTML5 and JavaScript, and built using the Apache Cordova framework to run on mobile devices, specifically on the Android operating system. This mobile app sends data to the remote application server through the AJAX, which is then stored into the database and shows the corresponding information in the map panel of the dashboard.

Technologies used

All technologies, frameworks and plugins used to build this mobile app are discussed below.

- HTML5 (HyperText Markup Language) – W3C designs HTML5 as markup language to develop rich webpages and provides support to mobile technologies such as location-based services and geolocation[27].
- JavaScript – This is a lightweight client-side scripting language that enables executable content in static HTML webpages to make them dynamic[28].
- Asynchronous JavaScript and XML (AJAX) – This is a new technology, a term coined by Jess James Garret in 2005, for synchronous and asynchronous communication with web applications and compatible with any programing language because of its cross-platform and cross-browser support[29–31].
- Apache Cordova – This provides an open-source mobile development framework to build mobile apps using HTML5, JavaScript, and Cascading Style Script (CSS). Apache Cordova provides a set of plugins to establish communication between an application and device-specific features such as GPS, camera, battery, storage, etc.[32]. The hybrid mobile applications are platform-independent and can be executed on all devices[32,33]. In this mobile app, geolocation and camera plugins are embedded to access the GPS and camera functions of mobile devices, which will help the decision-makers.

Following are the salient features of the FFR mobile app:

- Simple and responsive user interface for easy reporting.
- Form-filling is available with dropdown selection for ease and fast reporting.
- Geolocation API to fetch latitude and longitude using in-built mobile GPS.
- Automatic retrieval of date and time on the mobile device.
- Camera API to upload an image either by selecting it from the device gallery or capturing an image from the camera.
- Local storage is enabled to store reported observations when internet connectivity is not available.

As explained in Figure 4, the android-based FFR mobile app has been developed to achieve the goals of gathering data on forest fire events, forest fuel, species affected, fire type, causes of wildfire, etc. and thus transfer field data to the server for further monitoring by risk experts. The risk experts (Principal Chief Conservator of Forests, PCCF) visualize and analyse these incidents through spatial location and images on Google Maps, sent through the mobile app, and then, send the command to the concerned forest guards using SMS feature provided in the dashboard. These two methods are designed and developed in such a way to ensure integrity and safety of the environment and the public.

Web dashboard (server-side application)

After the reporting of a new forest fire event through a mobile app, the fire location is visualized on the map along with the image and related fields by the concerned Forest Department personnel over the web dashboard for further necessary action. The user interactive dashboard is developed using PHP (server-side programing language), HTML5 and the JavaScript, and database is PostgreSQL with spatial extension. This dashboard comprises of the functionality to send SMS through the info window of the point marker, using which the administrator or controller can send the required action information to the mobile number of the field personnel who have recorded particular points. Besides, the dashboard provides an option to download all the reporting points in CSV format.

FFR mobile app development approaches

The first step before development of the FFR mobile app was discussions with Forest Department officials, focusing on the active forest fire data collection using participatory sensing approach and analysis process which will be helpful in monitoring of forest fires. This discussion was conducted iteratively until both parties were satisfied. After each discussion, the components were analysed

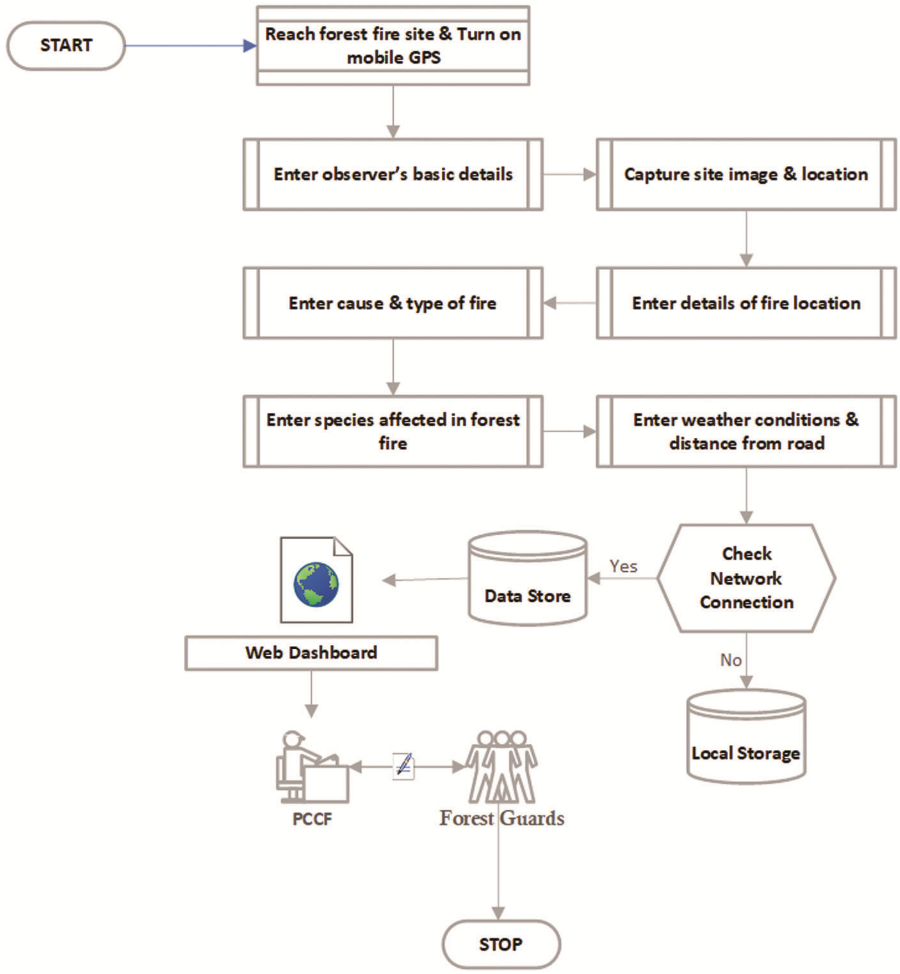

Figure 4. Methodology of the FFR mobile app.

line-by-line, breaking them into distinct units of meaning, codes were allocated to each field and finally, they were labelled to be clustered into categories. This set was then re-evaluated and discussions held with Forest Department officials which attributes were relevant and irrelevant in forest fires monitoring and analysis. Following are the major processes involved in developing the FFR mobile app.

(i) Nowadays, mobile platforms are moving towards disintegration rather than amalgamation, and disintegration can be seen across platforms as well as within the same platform. The mobile platforms are different with respect to programming language, software development kits, supporting tools, user interfaces and user interaction metaphors. However, mobile apps of the same platform also have different memory, random access memory, screen size, graphical resolution, operating system versions. Almost every mobile app developer considers this as a huge challenge on a regular basis. For FFR mobile app development, the project was set to minimum Android version 4.4 (KitKat) to maximum Android version 9.0 (Pie). To support different screen sizes, the responsive user interface was designed and tested on an emulator to support different screen sizes – 320, 480, 600 and 720 dp. Therefore, this app is executable in almost any Android-based mobile device.

(ii) Another task in mobile app development is choosing open source or closed source platform. Android is an open source which is easily modifiable according to user's choice, while iOS and Windows are closed source platforms in which modifications are not allowed. Therefore, FFR mobile app development was done on open source platform, i.e. Android with full functionality of modifying its services.

(iii) The major concern while developing the mobile app was data. Suppose, the FFR mobile app will be used by forest guards in forest where the network signal will be weak or unavailable. Thus, the app should have the capability of storing data in offline mode to prevent data loss in case of unavailability of signals in mobile phones. Therefore, offline saving of end-user data has been implemented in the FFR mobile app using Indexed Database API 2.0.

(iv) This is a hybrid mobile app developed using Apache Cordova framework in order to reuse some portions of its code for different operating systems and

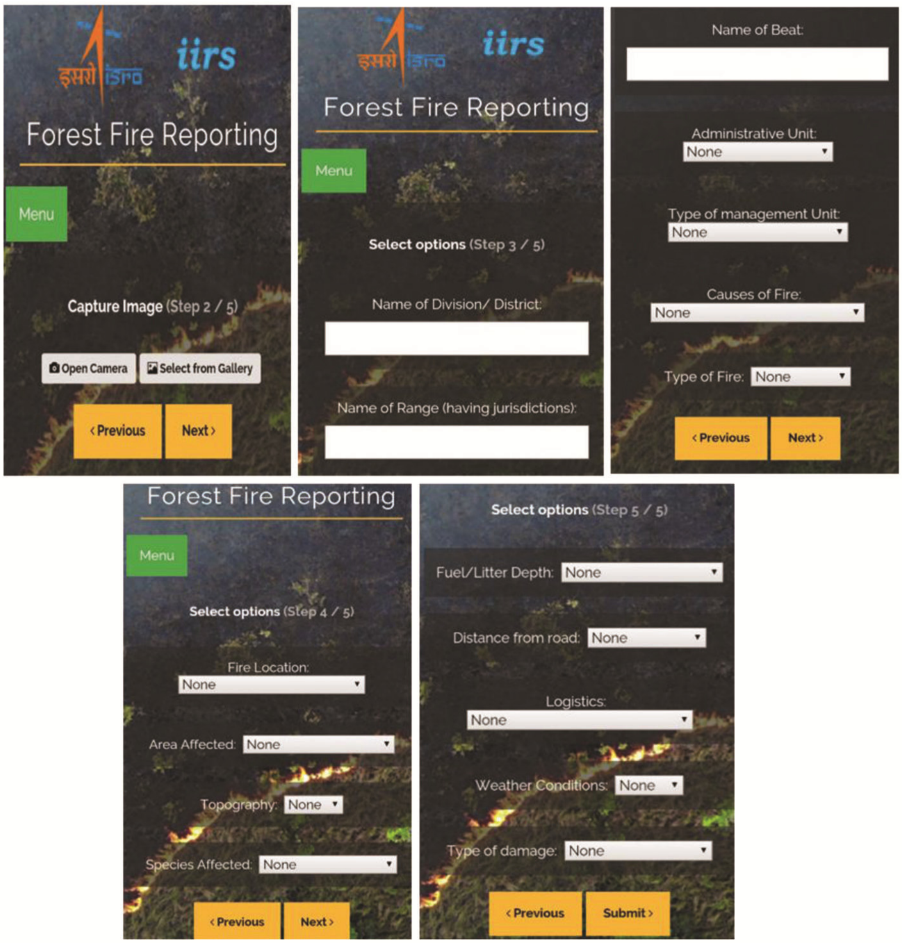

Figure 5. Screen of the FFR mobile app.

devices, rather than writing from scratch. The hybrid apps development saves time and effort of re-coding, and budget for hiring different developers for different platforms.

(v) To provide functionality of full duplex communication between forest guards and Principal Chief Conservator of Forests (PCCFs) during forest fire controls where making calls is not possible, SMS functionality is provided in mobile app and web dashboard. Using FFR mobile app, forest guards will raise queries/questions related to active fires, and these queries will be prompted on the web dashboard from which the PCCFs can respond through SMS to the forest guards.

Case study

The geospatial solution of forest fire reporting has been transferred to the Jammu and Kashmir (J&K) Forest Department, and is in use by the officers in hazardous areas; it has detected many forest fire incidents in J&K. This mobile application can record the following data: division, beat, administrative unit, management unit, cause of fire, type of fire, species affected, area affected (ha), topography, fuel/litter depth, distance from the road, logistics, weather conditions, type of damage, latitude and longitude.

Since October 2018, over 500 fire incidents have been reported from 13 divisions/districts of J&K using this mobile app. This is a good tool for creating further awareness and for learning indicators devised from end-user data.

Figure 7 shows a pie chart of forests/tree species affected. Figure 8 represents the information link as a line between fire location (blue colour) and species affected (yellow colour) in these locations; the round nodes depict the number of data records. Figure 9 shows the causes of fire under varying weather conditions; for example, in cloudy weather fire incidents were reported through this citizen-centric tool due to leakage from farm field, rolling of stone, controlled burning, etc.

Discussion and conclusion

As suggested by Berkes and Folke[34], a suitable 'mechanisms by which information from the environment can be received, processed and interpreted' is required to catalyse

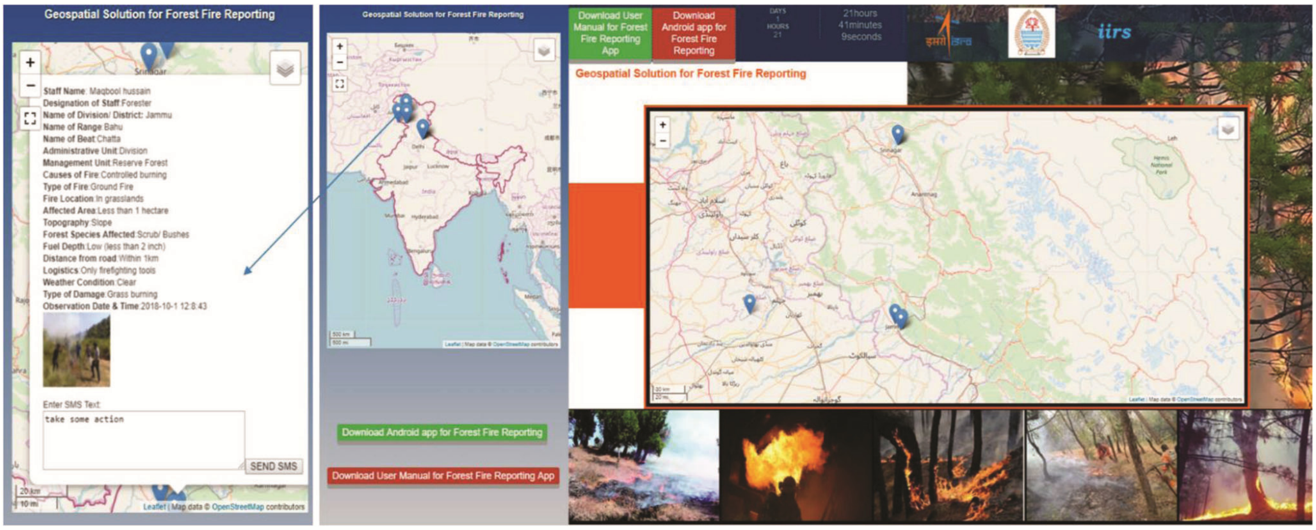

Figure 6. Web-monitoring dashboard for end-users of forest fire data.

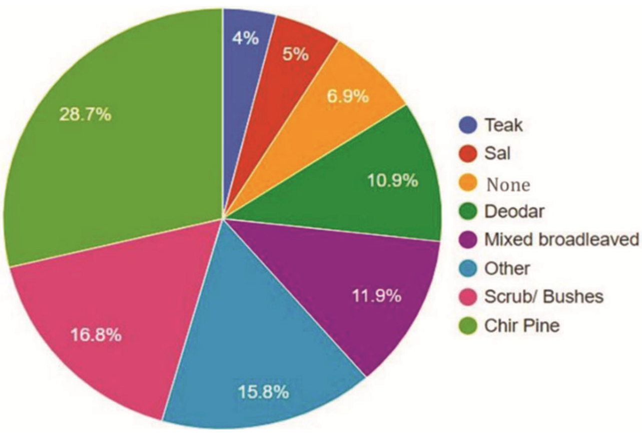

Figure 7. Pie chart of total species affected due to forest fires.

the community resilience on multiple social and ecological fronts, and decision-making policies[35,36]. The present study shows that a citizen science can be key to the current realm in disaster responses that represents a different transition from each mapping activity. From last few decades, the lay mapping through citizen science approach is becoming a common tactic in identifying and providing solutions to real-world problems specifically in disaster and environmental responses. Such mapping approaches with real-time or near-real-time data collection feature increases societal and technical values.

By considering citizen science wherein general community involve in surveying and data collection, leads to the geospatial solution for wildfires demonstrating how geospatial technology can be used in societal solutions[37], and the role of information and communication technology in governance[38].

This geospatial solution was initially executed in the J&K Forest Department and showed good effect by receiving more than 500 fire incidences since October 2018. This geospatial solution has been transferred to Uttarakhand Forest Department and a workshop was conducted with 36 forest officials. However, the system is in beta stage and few modifications are in progress on consultation with forest officials to better meet the needs of forest fire data collection.

Figure 8 depicts the interconnected relations relationship between species affected and the type of forest in which fires occurred. The entities are displayed as blue and yellow circular nodes. The blue node is forest type and yellow node is species affected, and lines show the relationship between them. In the figure, the blue node 'in open forest' is the biggest due to its highest number of records. The thickness of the line connecting to 'chir pine' depicts that the maximum number of forest fires were reported in 'in open forest' in which 'chir pine' species were the most affected, whereas 'teak' was the least affected species in 'in open forest'.

Figure 9 shows the relationship between weather conditions (yellow node) and causes of forest fire (blue node). For instance, one can learn that in cloudy weather, forest fires occurred due to leakage from the farm fields, rolling of stone, controlling burning, etc.

Therefore, these networking analytics can help decision-makers or professionals to learn and visualize the relationship between various entities.

In conclusion, we highlight the implementation of a participatory sensing approach in forest fire disasters, which is a traditionally adopted method in surveillance studies where experts of risk management will control the behaviour and outcome of incidents being mapped through the forest fire mobile app[39]. The implementation plan of such geospatial solution to report active forest fires in different parts of the country is in progress. This

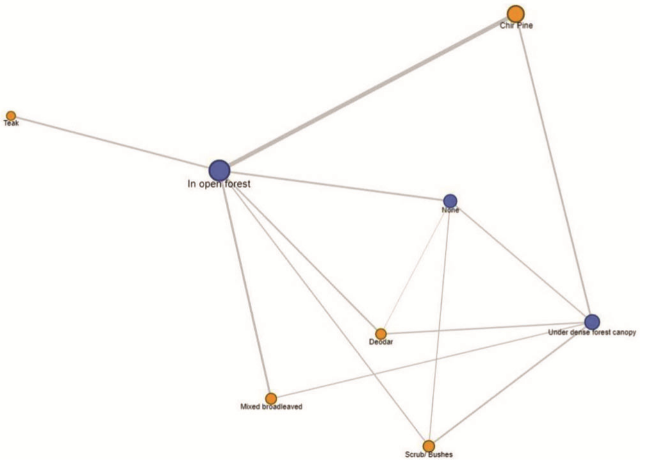

Figure 8. Species affected at different fire locations.

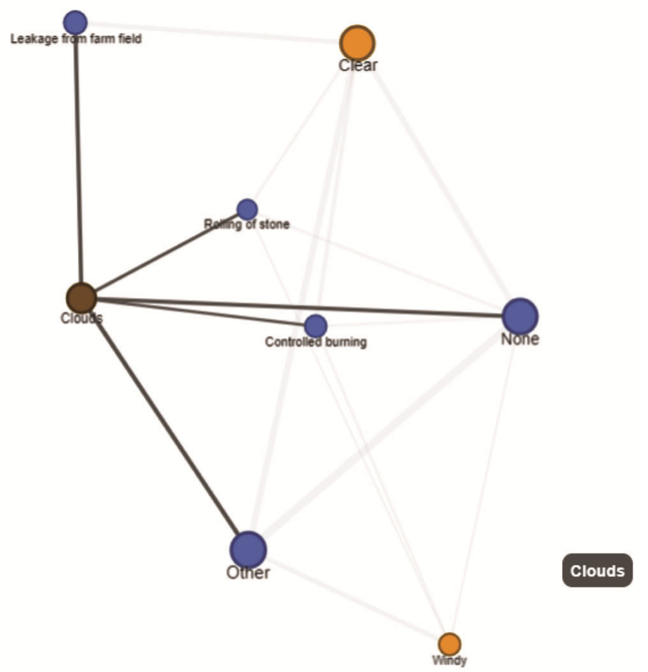

Figure 9. Causes of forest fire in different weather conditions.

implementation plan is a part of the Indian Bioresource Information Network (IBIN) national project and will be available on the IBIN portal once it reaches the completion phase. The IBIN project is an initiative of the Department of Biotechnology, Government of India with an aim to enhance distributed database on bioresources, and integrate advanced analytical and citizen-centric tools to build a national geoportal on bioresources of the country.

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