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Forest Fire Risk Zonation Using Geospatial Techniques and Analytic Hierarchy Process in Dehradun District, Uttarakhand, India

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Abstract:

Forest fires are one of the major natural risks in the forest of Uttarakhand. In such areas, fire occurs frequently and there is a need for global approaches that analyze wide scenarios of factors involved. It is impossible to control nature, but is possible to map forest fire risk zone (FFRZ) and thereby minimize the frequency of fire. The aims of the present study are 1) to set up and analyse the FFRZ over forested region of Dehradun 2) to see whether these forest fires are natural in nature or deliberately caused by people living adjacent to forest 3) to find firs prone areas and their prioritization. The model deals to combine geospatial data by Geographic Information System (GIS) technology to construct the FFRZ map. Influencing factors like vegetation moisture, slope, aspect, elevation, distance from roads, and vicinity of settlements have been taken into consideration. These variables were weighted based on their impact on the fire risk. Around 3.13% of total forested area was found to be in very high risk zone and 50.25% area was found to be in high-risk zone. The distribution of fire data over the FFRZ map shows that a very small part of them (1.26%) falls under very high risk zone and majority (98.74%) comes under high and moderate high risk zone areas. It indicates to a great extent that major part of forest fire is natural in nature and non-intentional. The people living nearby have the least role in causing these forest fires.

Keywords: Forest Fire risk zonation, Analytic hierarchy process, Normalized Difference Water Index

1.0 Introduction:

Forest fires are one of the most important sources of land degradation that lead to deforestation and desertification processes. Forest and wild land fire are considered vital natural processes initiating natural exercises of vegetation succession. However uncontrolled and misuse of fire can cause tremendous adverse impacts on the environment and the human society. In India, about 2-3 % of the forest area is affected annually by fire and on an average over 34,000 ha forest areas are burnt by fire every year. Some incidental but majority are deliberately caused (Kunwar & Kachhwaha, 2003). Remote sensing and GIS is important tool for mapping and management of forest fires. The first application of forest fire dates from 1960 when several aerial infrared scanners were tested for fire spot detection (Chuvieco & Congalton, 1989). Additionally remote sensing has been effectively used in fire hazard rating system. In India, foresters have been debating the issue of forest fire control for a long time, but the paucity of information owing to the lack of qualitative and quantitative studies on forest fire and its effect has not resulted in any defined approach to control the forest fires. Kimothi & Jadhav (1998) have studied forest fires in the Central Himalaya and have developed methodology to monitor and assess the damage. A forest fire risk model was developed by Jain (1996) for Rajaji National Park. Kunwar & Kachhwaha (2003) have done forest fire hazard mapping in Himalayan region of Uttaranchal and Sikkim.

FFRZ are locations where a fire is likely to start, and from where it can easily spread to other areas. A precise evaluation of forest fire problems and decision on solutions can only be satisfactory when a fire risk zone map is available (Jaiswal, 2002). Understanding the behaviour of forest fire, the factors that contribute to making an environment fire prone, and the factors that influence fire behavior are essential for forest fire (Chuvieco & Congalton, 1989). In the present study, an attempt was made to prepare a forest fire risk zone map by integrating the information out of satellite data, topographical and other ancillary data from GIS for the Dehradun district, Uttarakhand, India, (Fig 1). The valley of Doon is surrounded by Shiwaliks in south-west and lesser

Himalaya in north-east direction. About 52% of the Doon valley encompasses subtropical moist deciduous Sal forest (Mukesh *et al.*, 2014). The study area also harboured 86 Medicinal plants, of of high commercial value (Rawat *et al*., 2009). It also includes the major elephant corridor like Kansrao - Barkote and Chilla – Motichur area (Menon *et al.* (2005). This study is an attempt to exploit the capabilities of remote sensing and GIS techniques and to suggest an appropriate methodology for FFRZ mapping. This GIS-based model seems to be a reasonably good approach for the conditions in India, where a major part of the forested land is being encroached upon by the population (Jain *et al.*, 1996; Roy *et al.*, 1991). Such maps will help forest department officials to prevent or minimize fire risk activities within the forest and take proper action when fire breaks out (Chuvieco & Sales, 1996).

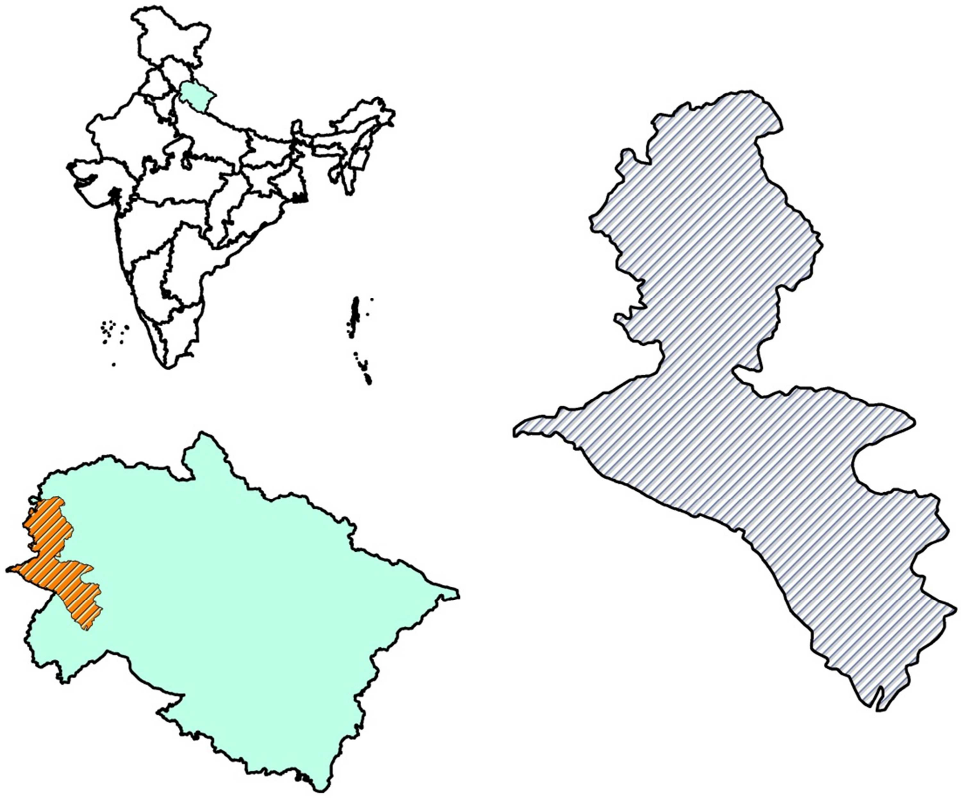

Fig 1. a) Uttarakhand in India b) Dehradun in Uttarakhand c) Dehradun district

The Analytic Hierarchy Process (AHP) method commonly used in multi-criteria decision making exercises was found to be a useful method to determine the relative weights. Saaty has shown that weighting activities in multi-criteria decision-making can be effectively dealt with via hierarchical structuring and pairwise comparisons. Pairwise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements (Saaty, 1980). Vegetation type/ density are prominent factors leading to forest fire apart from climatic and physiographic factors (Subin *et al.*, 2010). However we have used Normalized Difference Water Index (NDWI) as an important parameter and as a substitute for vegetation type/ density in the absence of reliable satellite data of appropriate period for the study area. Since NDWI is calculated using a water absorption band, it should be more closely related to live fuel moisture than the chlorophyll absorption-based NDVI. Sims and Gamon (2003) have reported the suitability of NDWI for the application of monitoring live fuel moisture. Fuel Moisture Content (FMC) is an important factor to forest fire risk prediction. The FMC in broad scale can be estimated by using the SWIR and NIR channel of satellite data (Xianlin *et al.*, 2008).

Dryness increases the flammability of the forest due to the fact that the moisture influences the spreading of the fire (Siachalou *et al.*, 2009). Elevation is a crucial physiographic variable that is associated to wind behavior and therefore affects fire capability (Rothermel, 1983), so it has a big role in fire spreading (Jaiswal *et al.*, 2002).

It is mentioned that humidity and temperature have higher influence on fire at upper altitude areas than lower ones (Hernandez-Leal *et al.*, 2006). Steeper slopes lead to less fuel moisture and less air humidity (Pandey & Barik, 2006). The vegetation in such slopes is mainly dry and catches fire easily (Lawrence *et al.*, 2006). Moreover, once the fire starts, it is likely to spread faster up-slope than down-slope and along steeper slope than gentle ones. The slope above 10^{o} has high fire risk when compared to flatter terrains. South aspect receives more sun light and exposure in the North hemisphere and therefore drier soil is more capable to ignition (Noon, 2003). The habitation and roads render the forest highly vulnerable to forest fire due to more intense human activity. The forested region near to settlements and houses are more capable to fire ignition because the accidental fire can be caused by housing density and inhabitants near the forest (Jaiswal *et al.*, 2002). The study area contains many settlements which possess high fire risk to the forest. In this study proximity to roads and habitation were significantly considered as important factor that also layout the occurrence of forest fire.

In this study spatial modelling has been done to obtain the combined effect of aforesaid variables. Different weights were assigned as per the importance of the particular variable. Highest weight was given to the vegetation moisture as it indicates fuel ignition, because fuel contributes to the maximum extent due to inflammability factor. The second highest weights were given to settlements and road as they allow local people, graziers, and tourists to go in to the forest and cause fire. Then comes slope and aspect because sun facing aspects receive direct sun rays and make the fuel drier and highly inflammable; higher slopes contribute to convectional preheating and easy ignition and spreading of fire. Finally it's the altitude since human infiltration decreases along the altitude.

2.0 Material and Methods:

The Survey of India toposheets on scale 1:50,000 became the source for basic thematic layers like road and settlements. Around 47 locations of human settlement found near the forestland were digitized. The whole road network was digitized. However the roads lying closer to forestland showed its influence on its adjoining forest (as can be observed in its buffer layer) in comparison to those lying completely in the centre of town area. The topographical factors like altitude, slope and aspect layers were derived from *Advanced Spaceborne Thermal Emission and Reflection* Radiometer DEM 30m data. Moderate-resolution Imaging Spectroradiometer (MODIS) data MOD09A1 provides Bands 1–7 at 500-meter resolution in an 8-day gridded level-3 product in the Sinusoidal projection. Each MOD09A1 pixel contains the best possible L2G observation during an 8-day period as selected on the basis of high observation coverage, low view angle, the absence of clouds or cloud shadow, and aerosol loading. The MODIS Surface Reflectance products provide an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. MODIS data of 30th April 2008 was used to generate NDWI. The NDWI is then resampled into 29.5m pixel size, UTM projection with WGS84 datum and zone 44. Other data were also brought into same projection parameters. The fire data was downloaded from the national aeronautics and space administration (NASA) of amercia's website https://earthdata.nasa.gov/data/near-real-time-data/firms from the year 2000 to 2012 for the month of April and May since summer is at its peak during this period. Each active fire location represents the centre of a 1km pixel that is flagged by the algorithm as containing one or more fires within the pixel. The ArcGIS 10.1 and ERDAS Imagine 2013 software were used for carrying out the study. The details of methodology is explained via flowchart (Fig 2).

2.1 FFRZ model

Vegetation moisture (NDWI) was calculated using MODIS data as:

NDWI = ρ857- ρ1241/ ρ857- ρ1241

where ρ857 is the reflectance in a NIR reference band and ρ1241 is the reflectance at 1241 nm, which is within the water absorption band centred at 1200 nm (Gao 1996). Elevation, Slope and Aspect layers were prepared using DEM. Buffers which is within the water absorption band centred at 1200 nm (Gao 1996). Elevation, Slope and Aspect layers were prepared using DEM. Buffers were generated for road and settlement layers. All these thematic layers were classified (Fig 3) and then numerical ratings were assigned according to their influence on fire behaviour (as per values mention in table 1). The ranks of the classes of each theme were assigned in a scale of 1-4 by reclassifying them in such a way that higher rating is given to the class which has high positive relation with fire proneness than the class which shows lesser positive relation with it. The areas closer to the settlement or road are high fire risk areas and therefore are given higher ratings. The rating decreased with the increase in distance from the settlement or road. Similarly slope and aspect of the terrain also have indirect influence on fire risk as they control the vegetation density and composition.

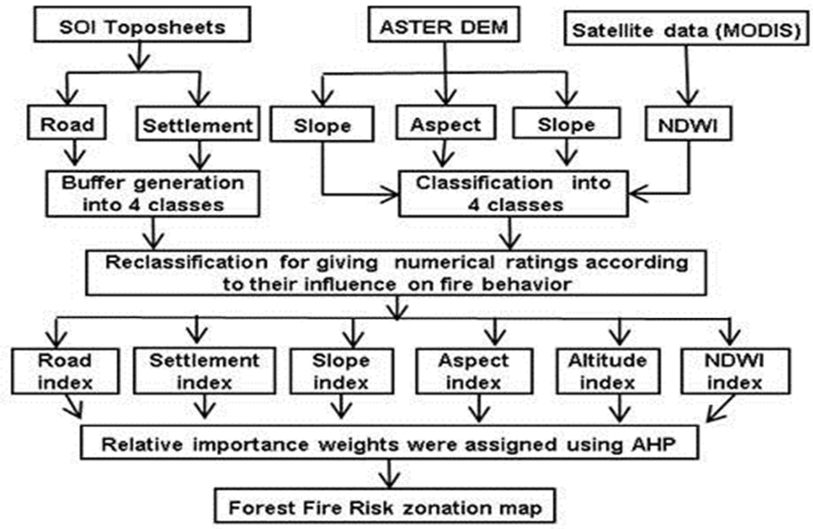

Fig 2. Flowchart of the methodology

Table 1. Weights assigned to variables and classes for forest fire risk modelling Variables Classes Ratings of hazard Fire sensitivity

S No	Variables	Classes	Ratings*
1	NDWI (MODIS)	<0, 0-0.1, 0.1-0.2, >0.2	4,3,2,1
2	Settlements	<500m, 500-1000m, 1000m-1500m, >1500m	4,3,2,1
3	Roads	<100m, 100-200m, 200-300m, >300m	4,3,2,1
4	Slope (in degrees)	<3, 3-5, 5-10, >10	1,2,3,4
5	Aspect	N, E, W, S	1,2,3,4
6	Elevation	<750m, 750.01-1500m, 1500.01-2250m, >2500m	4,3,2,1

*4= very high, 3= high, 2= moderate, 1= low.

After rating all thematic layers, AHP-derived weights were generated for each layer wherein pair-wise comparison matrix of the six variables viz. NDWI, distance from roads, distance from settlements, slope, aspect and elevation were done. The pair-wise comparison matrix was synthesized by dividing each element of the matrix by its column total. The priority vector can be obtained by finding the row averages. The weighted sum matrix was calculated following Saaty (1980), the consistency ratio was found out to be 0.093 which is less than 0.1, indicating that the calculation is acceptable according to Saaty's principle. The relative importance weight of different variables, obtained from the above analysis, were used in following linear additive model to arrive at the fire risk zonation:

FFRZ = [(0.37*NDWI) + (0.25*S) + (0.18*R) + (0.11*SL) + (0.06*AS) + (0.03*ELE)]

where S, R, SL, AS and ELE are coefficients applied for settlement, road, slope, aspect and elevation.
Based on the various statistics of different weights assigned through AHP, the map was reclassified into four classes as Low, Moderate, High and Very high to generate FFRZ map (Fig 3). The thematic layer of greenwash (proxy recorded forest land) digitized from SOI Toposheet was used to mask out the non-forest area and to represent the final FFRZ map for the Dehradun forest.

3.0 Result and Discussion:

The FFRZ map (Fig 4) showed that 3.13% of forestland falls under very high risk zone while 50.25% area lies in high risk zone (Fig 5). 636 fire points falling under Dehradun forest were considered to verify the fire risk prone areas. It was found that only eight fire points were falling under very high risk zone covering an area of 4226 ha.

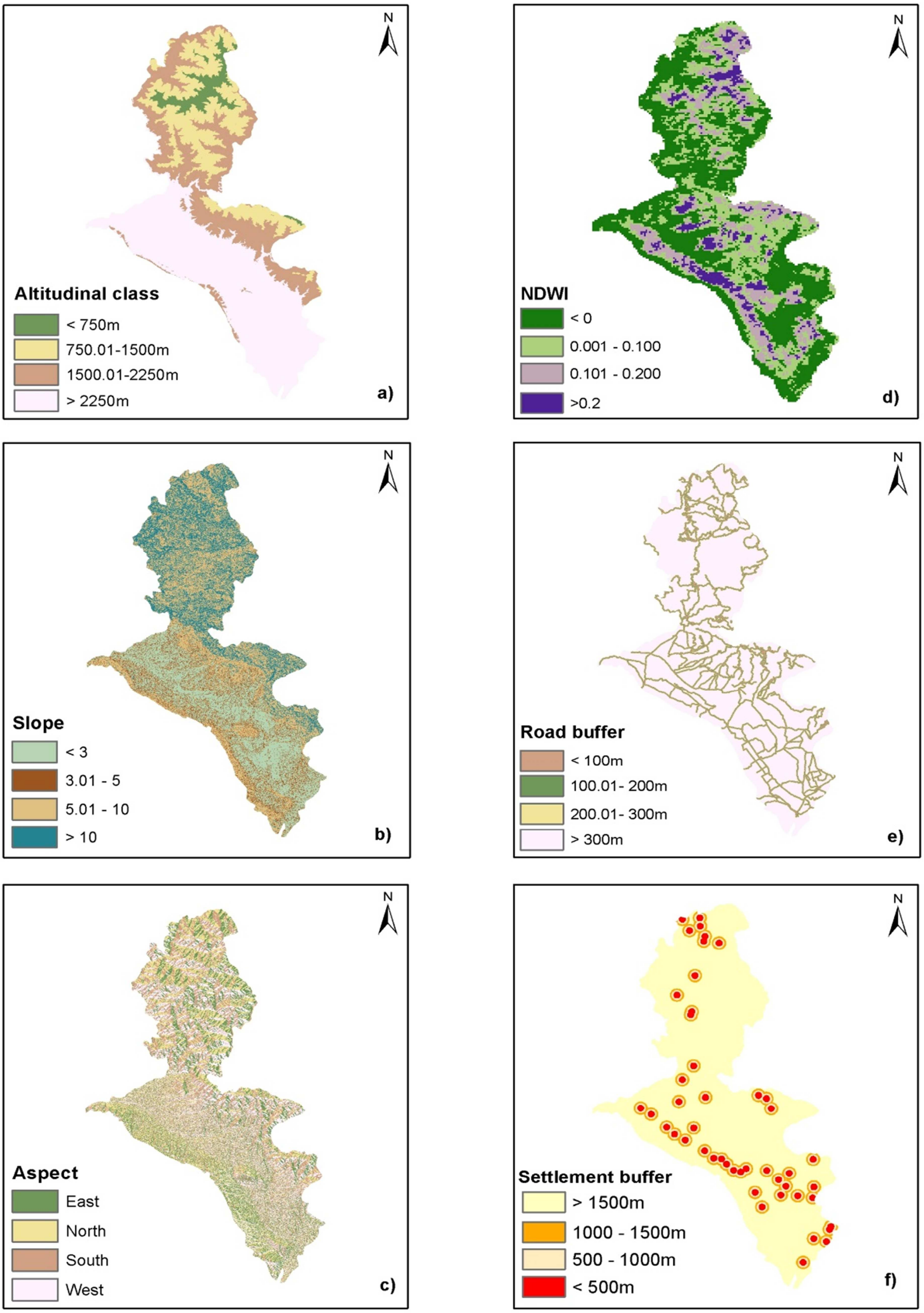

Fig 3. Variables classified into four zones.

It suggests that humans have least role in causing any fire incident in forest area. Around 47.48% fire points were lying in high risk zone and 51.26% of fire points were lying in moderate risk zone area (Fig 6). Thus the forest fires occurring in Dehradun forest are majorly triggered by nature. The analysis of fire points also revealed that 74.37% of these fire incidents have taken place in the month of April and May.

GIS analysis has taken into consideration a wide range of suitability parameters in identifying fire-prone area. Some areas identified as very high risk zone areas were Haldwari, Bhogpur, Jollygrant, Bhupal, Ankhandigram and Bhandi (Fig 4). These areas have predominantly Sal and Sal mixed forest. The forest department is suggested to monitor these areas on regular basis during summer season to avert any loss of forest trees due to forest fire. The map can be used to prioritize the area for monitoring forest fire. It is always advantageous to have a fire risk map to avert possible disasters caused by fire. It would also enable the Forest department in planning the main roads, subsidiary roads, inspection paths, etc. and may lead to a reliable communication and transport system to efficiently fight small and large forest fires. Thus the GIS along with AHP can be successfully employed in identifying of fire-prone areas and their management in the forested area of Dehradun.

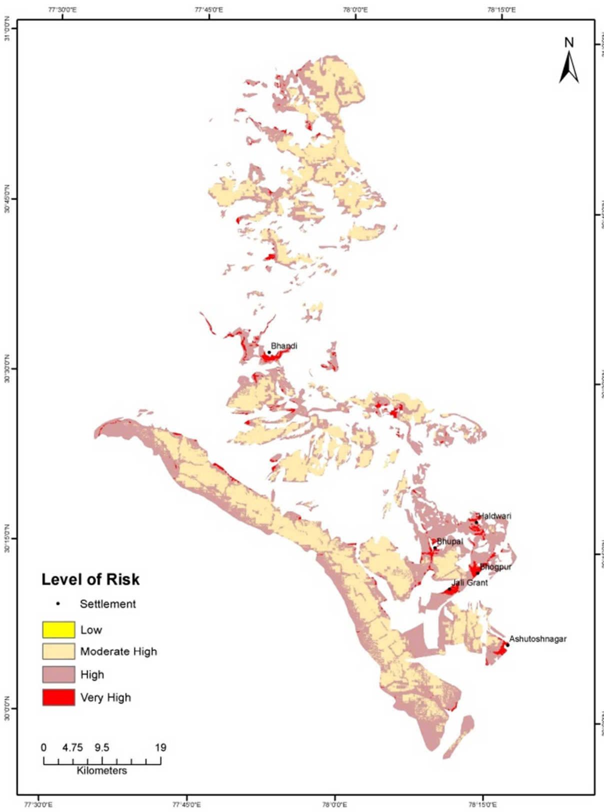

Fig 4. FFRZ map with settlement near very high risk zone

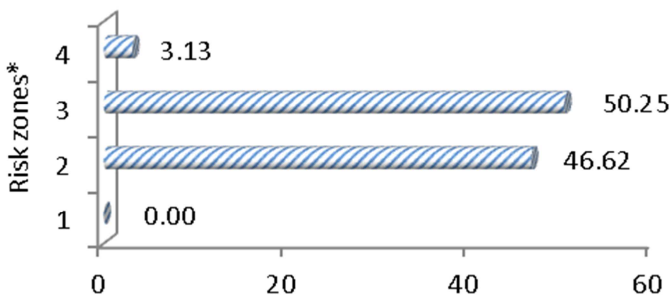

Fig. 5. Forest Area under various risk zones

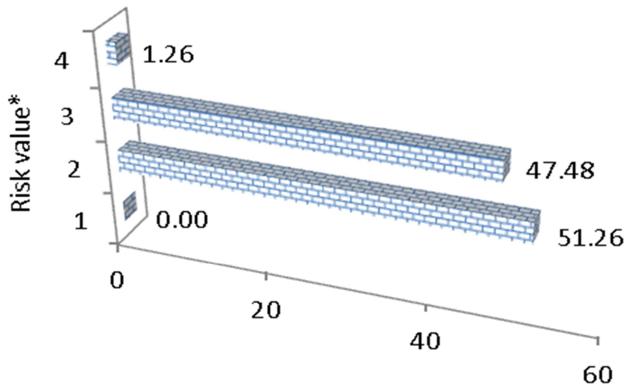

Fig. 6. Percentage of total number of fire points
(During 2000-2012, April & May months), (*Risk zones: 1= Low, 2= Moderate high, 3= High, 4= Very high)

4.0 Conclusion:

The fire data provided by NASA and satellite data available online can be efficiently used in carrying out preventive measures wherever possible for the welfare of nature and human society. The data used in case study via reliable approach like AHP helps to understand the nature of problem and the results thus obtained can be used for planning and management of forest resources. A further study on effected area due to natural forest fire in conjunction with local vegetation type and structure would further help in understanding how this natural fire is changing the local ecology and playing its role in plant succession.

5.0 Acknowledgement:

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