IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 8, Issue 4 Ser. II (Jul. – Aug. 2020), PP 51-60
www.iosrjournals.org

Forest Fire Damage Assessment using GIS in Uttarakhand – A case study

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Abstract
Background: *Forests are one of the important lifelines on the earth and significantly important for the living being. Forest fire is one of the major reasons for the destruction of these valuable green shields. Previous time forest fire occurred due to climate change, but at present, the significant forest loss happened through anthropogenic activities. The damage is not only concerned about forest loss but also the terrestrial ecosystem. Every year the Himalayan forest is very much destroyed by the forest fire, the study area Bagheswar and Almora districts depict one of the victims of these human-induced acts. With the reinforcement of climate change, to monitor the present day scenario of the forest fire, remote sensing data plays an enormous role.*
Materials and Methods:*We use multispectral and microwave data to monitor the forest fire with a comparative view analysis. We also use MODIS fire points to get an accurate location analysis. The fusion work of multispectral and microwave data performed to enhance work efficiency. Preprocessing is the mandatory initial step for both Landsat and SAR data. Landsat 8 preprocessing includes [20], [21] conversion of DN value to radiance and reflectance with atmospheric correction. Sentinel 1 data preprocessing [18] step is conversion from DN to db. [22]. After preprocessing, a relationship between satellites derived fire intensity and DEM slope has been derived with a strong negative trend.A LULC map has been generated to analyze the pattern of fires regarding settlement areas or anthropogenicprone areas*
Results: *Relationship between Slope and Forest Fire Intensity played important role to determine the vigorous pattern of forest fires in hilly regions. The damaged area assessment due to the forest fires shows highly affected zones. We also shown trend analysis of forest fire in Almora and Bageshwar district to get a clear ideaof forest fire in the area since 2015.*
Conclusion:*In hilly areas, forests are primary sources for livelihood in mountain rural areas. So its preservation is very important. With the help of forest fire assessment, government or agencies can plan better policies and methods to preserve the forests.*
Keywords: *Forest fire, Geographic Information System, Sentinel 2, Landsat 8, SAR Data, Trend Analysis, Fire Intensity, Fire Damage Areas.*

Date of Submission: 12-08-2020 Date of Acceptance: 28-08-2020

I. Introduction

Forests are considered as the soul regarding the preservation of life on earth. From terrestrial, ecological to the biological forest has a great impact on livelihood. The climatic variations also depend on forest cover change analysis. According to the report of FSI (2019), in India, the forest covers 21.67 percent of geographical area out of which the maximum part lies in the Himalayas region. Focusing on Uttarakhand state, its forest covers 45.44% **(**FSI report 2019**)** with an increment of 0.03% from 2017. Forest is a viable source of various products and resources should have the right to be preserved. Hilly forests are defined as a land with minimum an elevation of 2500 m above thesea.

With the development, human interference has changed the terrestrial ecosystem accordingly. For the expansion of the economy and the development of farming forests needed to be cleaned but still it is hard to predict the nature and pattern of wildland forest fire by any policies or pre-planning. Forest fire can be categorized in ground, surface and crown fire[1]. To monitor and analyze forest fire, remote sensing and GIS has emerged as an essential tool worldwide. Many researchers have published the extensive use of geospatial techniques for fire acquisition. Optical and Microwave data are being used in forest fire mapping on the basis of different temporal and spatial scales. Limitations of the optical data, studies and researches tend to use microwave data. The fusion work [2] always gives the better results as it combines both data to manipulate individual data for a better analysis [3], [4], [5]. A lot of researchers have done projects on Forest fire damage assessment to emphasize the importance of the studies in a real world perspective [6] have also used MODIS active real time fire data on a temporal basis in the study. There is also VIIRS data present for real time active fire location but in this study the data used was MODIS Aqua data [7], [8]also have used MODIS data to detect fire in Uttarakhand, which gives a wide view about the fire points. For thermal bands, Landsat [9]is used. To detect forest fires, Landsat data has been considered as the most useful [10], [11] used Landsat NDVI and LST parameters to map forest fire. With the help of multispectral data, Composite Burn Index was calculated [12] to detect the fire damaged area [13], [6] and many researchers have applied multispectral optical data for forest fire assessment[14] explored the use of SAR data in forest fire. The cloud and forest canopy layer penetration capability and all weather coverage of SAR data opened a new way to explore advanced methodology using C band and polarization[15] for better forest fire projects [16].

This study is also focused on C bands with VV polarization capturing mode. The study is focused on the damaged areas of forest due to forest fires in Bageshwar and Almora districts of Uttarakhand. MODIS fire points, Landsat 8, DEM and SAR data are used for mapping and analysis. The fusion of SAR and Landsat8dataenhanced the classified LULC mapping and the accuracy assessment in the results of damage areas. The study aims to find out the Forest fire damage assessed areas based on fusion workOf SAR and optical data to enhance its efficiency [17].

II. Study area

It is located on a ridge at the southern edge of the Kumaon Hills of the Himalaya range and surrounded by thick forests of pine and fir trees. Almora and Bageshwar districts (fig 1) are top most forest rich areas of Uttarakhand that's why these two districts are taken out for fire damage assessment. The areal extension of the districts is from **30.320789 N** to **29.432131 N** and **79.024109 E** to **80.146973 E**.

The average altitude of Almora district is 1811 m and For Bageshwar it is 1004 m elevation, whereas the northern part is always under snow cover with an increasing altitude than average. Forests on land above 1500 m from sea level with slope are defined under mountain forests. Mountain forests come under fragile ecosystems because of extreme climatic and weather conditions. Mountain forests are useful for landslide prevention, rock falls barrier, biodiversity, and water runoff increment. Dry climate makes the forest fire worse. Main anthropogenic causes of forest fire in hilly regions are electricity lines, campfires, and discarded cigarettes. Human- caused climatic changes are also the one of the main factors in increasing numbers of forest fires in hilly regions.ConsideringBageshwar the total area of 2290km^2 and1381km^2 area are under forest cover [7]. District Bageshwar has varied types of forest. Each of these has a special characteristic in terms of Biomes and Biodiversity. There are intermingled features in forest in between the demarcated climatic zones. Each type of forest has its own regime of other biotic life flora and fauna. The forest vegetation in the district varies from Northern Dry Mix Deciduous Forest in the Lesser Himalayas to Alpine meadows. In between the two extremes from Lesser Himalaya to Greater Himalaya there are many variations. About Almora forests occupy nearly 51% of the district. Changing thermal conditions and varying relief control the distribution of natural vegetation. The forests have plenty of broad-leaved evergreen plants like Baanz, Buransh. Higher altitudes have Deodar forests. The study area is focused on the pattern, trend, behavior and intensity of forest fires in Almora and Bageshwar districts. The data has been taken out of November and December 2015, as rural people used to burn the forests to convert them into pasture or agriculture lands or shifting cultivation for grazing and harvesting respectively. The reason behind November and December data is that the both months come under dry season, so the frequency and intensity of fire gets increased due to favorable climatic conditions for fire.

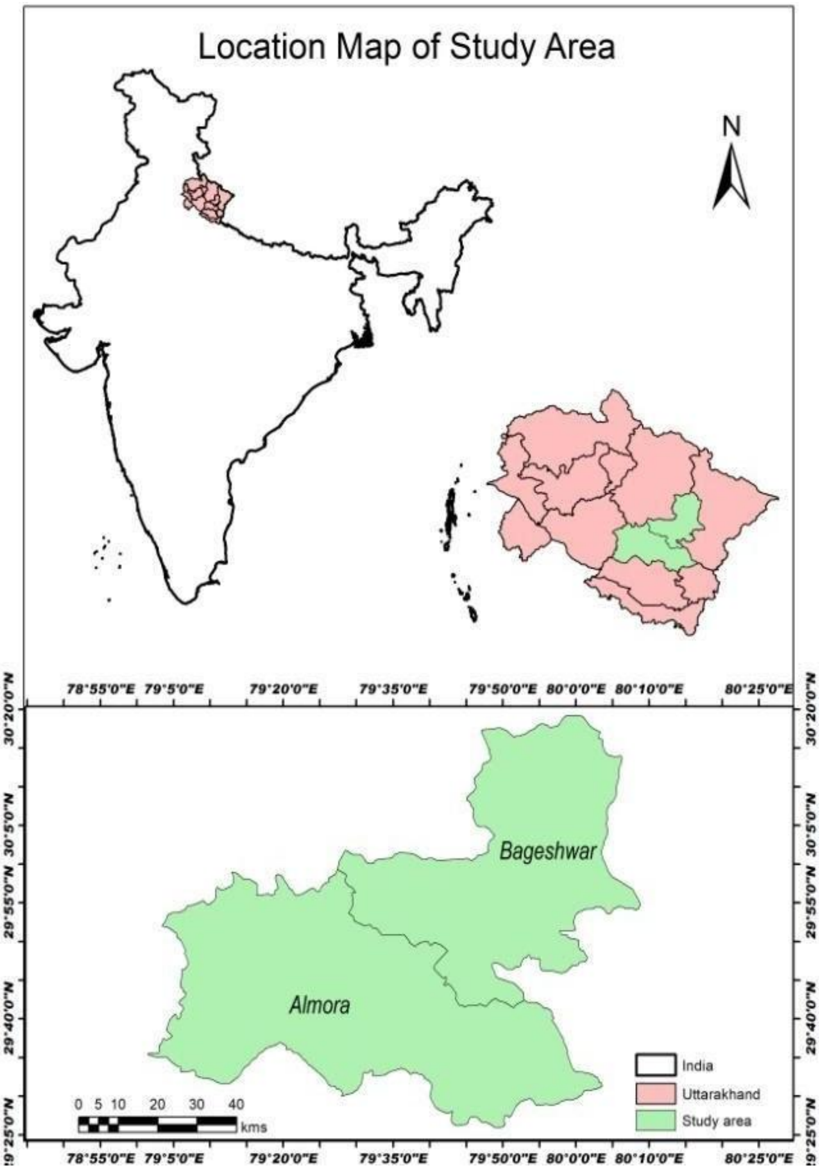

Fig 1: Study Area Map

III. Materials And methods

The study attempts the fusion of Landsat 8 and Sentinel 1 data approach for forest fire damage assessment mapping. The study is focused on the areas that are highly affected by anthropogenic activities. Multispectral and microwave data are used to enhance the working efficiency with satisfactory results in hilly regions. To extract the maximum data of forest fires, thermal bands of MODIS optical data (MODIS Terra and MODIS Aqua) have been opted as it gives the active fire points four times a day [6]. Visible bands, Near Infra-Red, Short Wave Infra-Red and Thermal Infrared bands, Cirrus and coastal aerosol bands of Landsat 8 have been used to detect the pattern in land use. To overcome the coarse resolution in Thermal bands (100 m) and limitation to penetrate ability through cloud and forest canopy, terrain deflection and atmospheric noise removal efficiency, Sentinel 1data(single C-band synthetic aperture radar through Dual Polarization VV characteristic) has been combined with Landsat 8 data. ASTER Global Digital Elevation Model at a spatial resolution of 30m has also been used to evaluate the importance of elevation in the proposed work.

MODIS Aqua Fire Datasets

Forest fire points were collected in December 2015 for damage area assessment and intensity interpolation over the study area.

3.1 Preprocessing of SAR data

It is essential to do preprocessing in SAR data before doing further analysis. Preprocessing is used to minimize the distortion impact that includes processing from "Orbit file" to "Terrain Correction". At last "Linear to DB" is done for data conversion to convert the raw data into the back scattering coefficients. The following chart and explanation are given below in fig 3 regarding the preprocessing of SAR data[18].

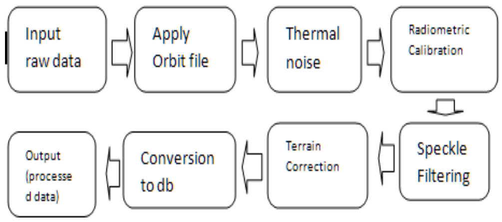

Fig 2: Sentinel 1 preprocessing workflow

(a). Apply Orbit File–The output of acquisitive SAR image raw file format cannot be read with fluctuation within it. This step helps to download the orbit state automatically for the image to provide an precise information of velocity and satellite position[18].

(b). Thermal Noise Removal–This process helps to mitigate with the unwanted noise problem that occurs in Sentinel 1. The thermal noise refers to the additional noise that is present in the inter-sub-swath texture. Removing the noise aims to stabilize the back scattering values in to the signal[19].

(c). Radiometric Calibration- SARradiometric calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. There are four different types of Level-1 products for the calibration of Look Up Tables (LUTs)thoseare ß0i, σ0i,γiandtheDigitalNumber (DN). For radiometric calibration following formula has been used, Value (i) = DNi / A_i^2

Where,

Value (i) = one of $\beta^{o}_{1,}$ °, or ϒ, or original DN

Ai = one of bet Nought (i), SigmaNought t (i), gamma (i) or DN (i)

Source; https://sentinel.esa.int/web/sentinel/level-1-preprocessing-algorithms

(d). Speckle Filtering– The electromagnetic pulses that return to the sensor generates a kind of granular noise (due to deflected back scattering) in the image. Speckle filtering has been used instead of Thermal noise removal method. It removes problems associated with tiny noise and features. There are various types of speckle filter, but for the study Lee Sigma has been used[18]**.**

(e).Terrain Correction– Range Doppler terrain correction can be simply denoted as Orthorectification. During electromagnetic pulses returning to the receiver, relief displacement creates an image distortion. To remove that barrier, terrain correction method is applied which minimizes the altitudinal deflection effect of the area with the help of a DEM[18].

(f).Conversion to Db– This is the last important step before analysis of a SAR data. This step is helpful to convert back scattering values into DN values and then DN value is rescaled into Db value. The algorithm in SNAP software for conversion is dB= 10* log (DN).

3.2 Data combination

Landsat 8 (moderate spatial resolution) and Sentinel1 (panchromatic high resolution band) data are combined to enhance the resolution of optical data which results in better visual LULC classification with the help of The Gram-Schmidt Pan Sharpening process.

Source https://www.harrisgeospatial.com/docs/GramSchmidtSpectralSharpening.html

3.3 Damage Intensity Interpolation

With the help of ASTER DEM (slope) data and the MODIS Aqua active fire points of the study area of the same time period of capturing the images, Kriging interpolation method has been applied to extract the intensity of damage area dueto forest fire in the study area

3.4 Intense BurnedAreas

Sentinel 1 data is the best way to evaluate the backscattering values of the MODIS fire points that lead to identify the areas which fall into high, mid and low forest fire prone ranges on the basis of classified values. A relationship between the back scattering value of Sentinel 1 data and slope map to correlate with altitudinal differences also has been developed for graphic representation.

3.5 Land use Land cover Mapping

LULC map is generated through supervised object based classification. With the help of damage intensity map and Slope relation data, LULC map is demarcated with fire damage assessment area that resulted to identify the highest fire damaged zone.

3.6 Trend Analysis

A trend analysis graph and map of different year's data (2015, 2016, 2017, 2018, 2019) has been produced to understand the changes in frequency, intensity and zonal area of forest fires over the passing of years. It is an attempt to understand the behavior of forest fires occurring towards the interference of human and nature.

IV. Results

4. Relationship between Slope and Forest Fire Intensity

Slope plays an important role to determine the vigorous pattern of forest fires in hilly regions. Graph fig 3 has been plotted to justify the hypothesis that the frequency and intensity of forest fires are founding lower altitude areas where the interference of humans ishigherthestrongnegative relationship (R^2=0.92) between slope and forest fire points has clarified the importance of slope in occurrence of forest fires. Along with increasing rate of altitude, the phenomenon is showing a reducing trend and at higher altitude the occurrence is tending tonull.

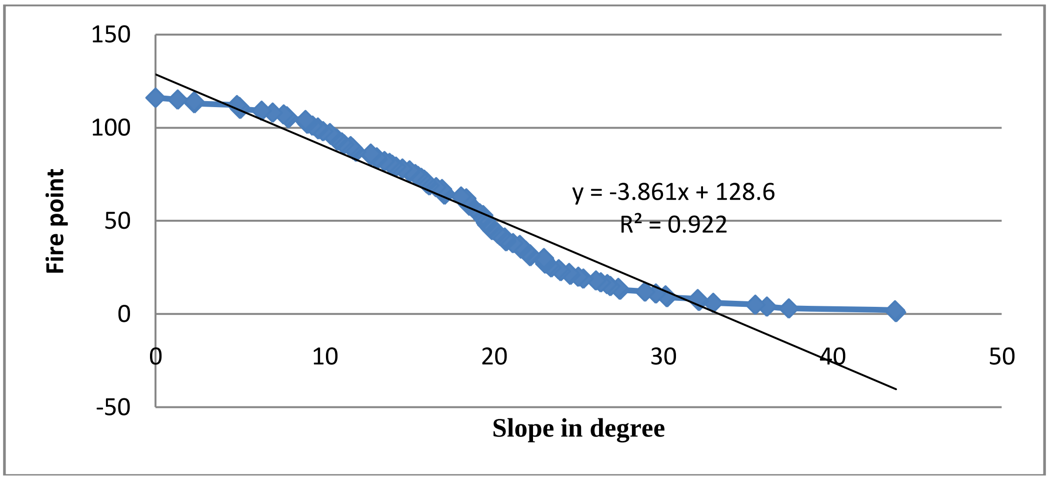

Fig3: The negative relationship of slope and occurrence of fire

1.2 Forest Fire Intensity Map

In fig4, satellite derived Fire Intensity has been mapped using DEM slope and 116 MODIS Aqua fire points from November 2015 to December 2015. The slope of the study area has been more than 70 degrees. The Kriging Interpolation method has been applied to estimate the fire intensified areas that were mostly destroyed. In the fig.2, it is clearly expressed that the moderate slope areas denote the high fire frequency compared to the high slope with low frequency of forest fires.

For agriculture land, pasture land, dwelling purpose and other basic need fulfillments, man has used to clear the forest purposely. As from the fire intensity map, it is clear that the most of the fires have occurred to the regions where settlements are found in majority compared to the high altitude areas that have a sparsely distributed population.

Thus, it has been found that the reason behindthe occurrence and the frequency of forest fire is fully anthropogenic, but the intensity can be controlled through climatic conditions.

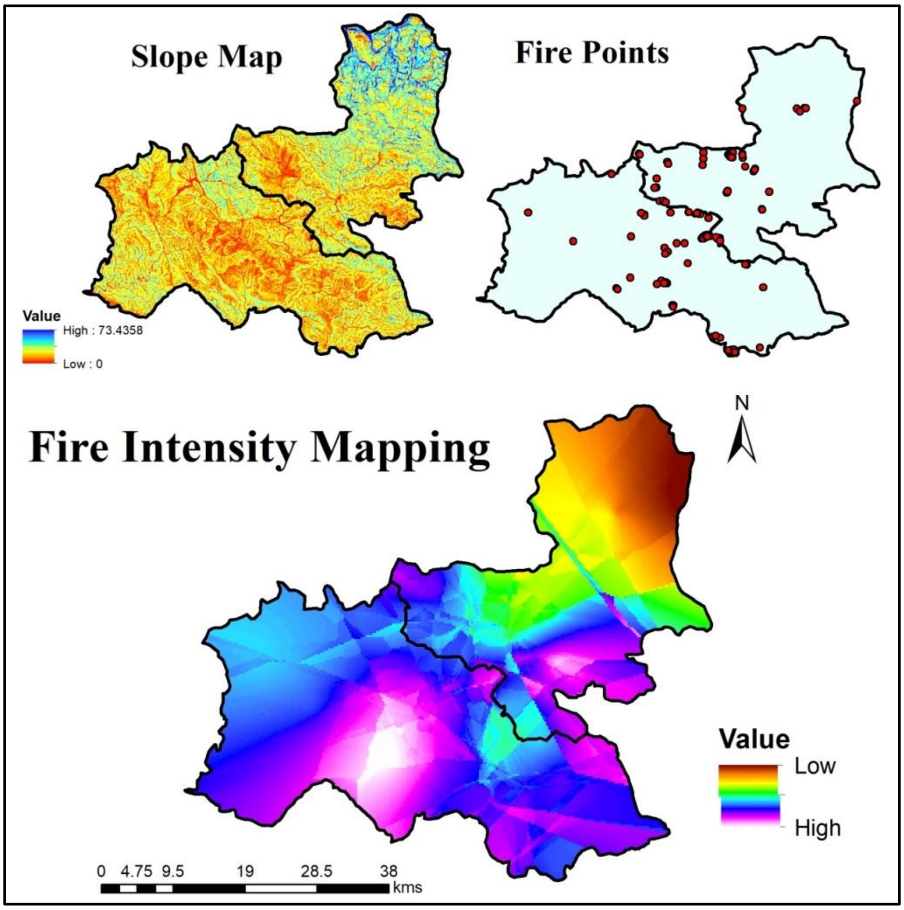

Fig 4: Fire Intensity Map

1.3 SAR Interpretation on the basis fire points

After pre-processing of SAR data, the back scattering values of the fire points are extracted to enhance the working efficiency. The fusion method is used to apply SAR data in a multiplicative way. The SAR data back scattering values depend on the object's texture, water content present in the object as well as the dielectric property of the object to make

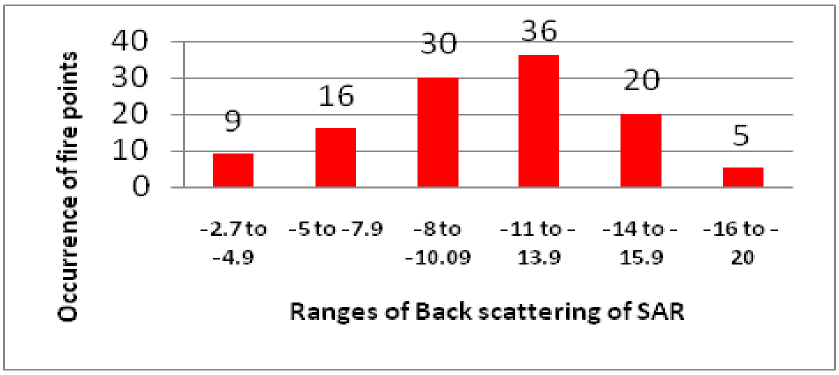

Fig 5: Occurrence of fire points in back scattering region

The image appears dark or bright. Hence, SAR data is important to measure the ranges of slope that fall underthemaximumforest fire points.Inthefollowing figure 5, the distribution of fire points in the back scattering regions are shown, where the highest points lie in the back scattering ranges between -11 to -14, and the second highest values fall in the ranges of -8 to -11. In the chart, most of the fire points are laid from -8 back scattering value to -14. These ranges are useful for the further assessment of fire damaged areas with respect to the landscape.

1.4 Relationship between SAR backscattering value and Slope of the area

A relationship between the back scattering values of fire points and the altitude of the same area has been plotted in the chart fig6. The negative relation indicates that lower the altitude higher the occurrence of forest fire.The R^2 value 0.023 depictsthe existing relationship but not strongly dependent on slope.

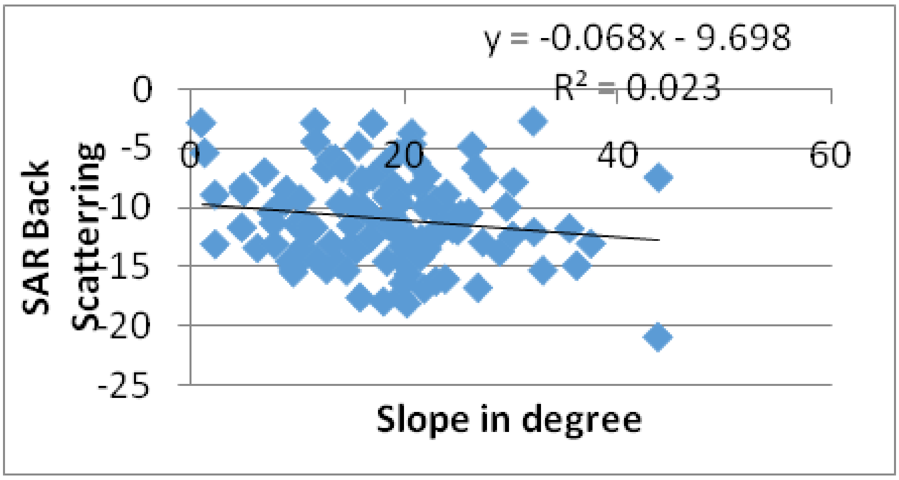

Fig6: Relationship between Slope and SAR Backscattering

2. Data fusion with LULC mapping

To get an abrupt idea of the study area, Land Use Land Cover is prepared. The study area Bageshwar and Almora is part of Uttarakhand, which cover the altitude variation from 800m to 2000m. In the 2015 image we classified the area into seven classes named below with area.

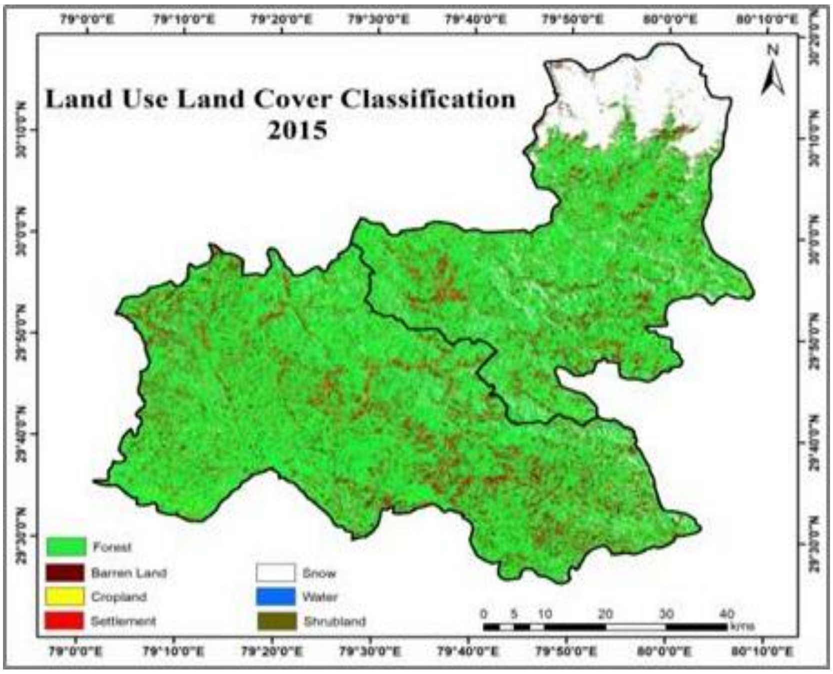

Fig 7: Land Use Land Cover Map 2015

Classification 2015	Area in Square km
Barren	91.0308
Cropland	262.675
Forest	3720.6
Settlement	197.304
Shrub land	514.979
Snow	569.284
Water	25.456

Fig 8: The LULC of 2015

2.1Forest Fire Damage Assessment

Fig 9 explains the damaged areas due to the forest fires. In the map, the overlapping section depicts the highest fire damage assessment. The map is extracted from the fire point's values of slope, SAR backscattering values and intensity interpolation method. The map is used to identify the dominant part that belongs to its forest cover. In both of the districts, occurrence of forest fire was too frequent due to anthropogenic activities.

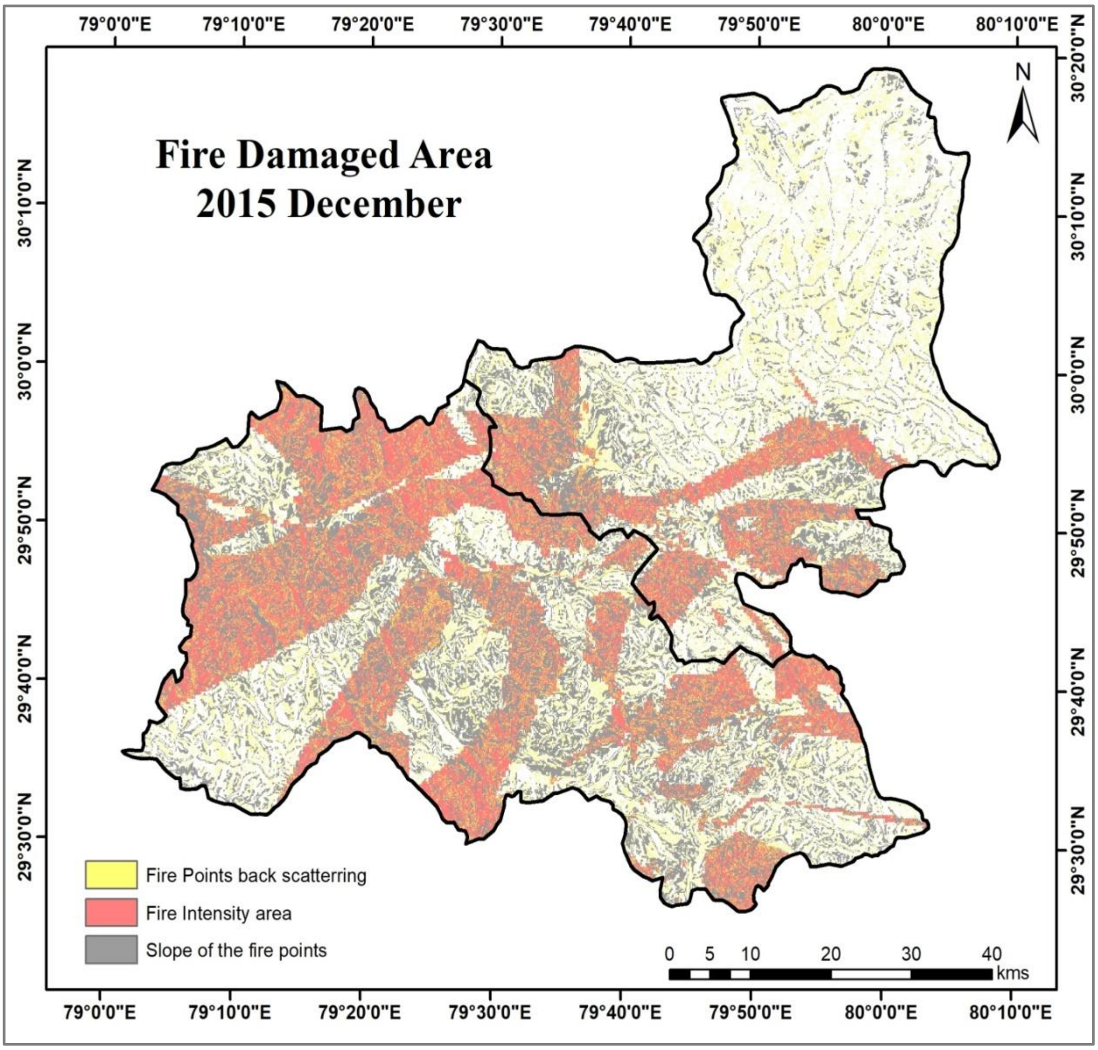

Fig 9: Fire Damage Assessment Map

2.2 Trend Analysis

To get a clear idea, a trend analysis of the occurrence of forest fire in the area since 2015 has been plotted. In the following fig 10 the map represents the frequency of occurrence throughout the years. It is clearly seen that the intensity is decreasing day by day; some of the reasons are people's awareness and some due to Government steps to protect the forest cover.

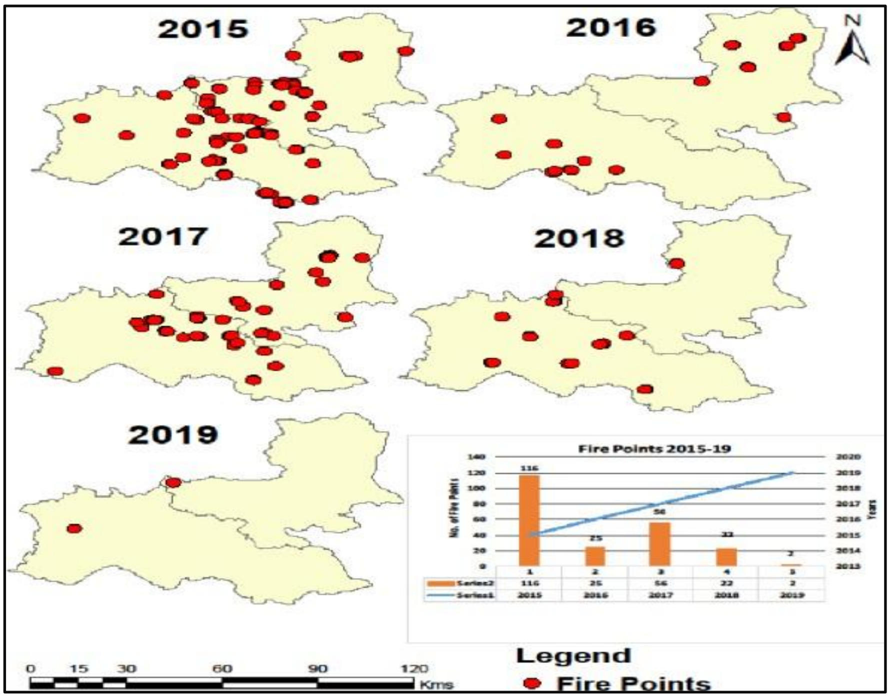

Fig 10: Trend analysis of fire points

V. Discussion

To achieve the objective, preprocessing is the mandatory initial step for both Landsat and SAR data. Landsat 8 preprocessing includes [20], [21] conversion of DN value to radiance and reflectance with atmospheric correction. Sentinel 1 data preprocessing [18] step is conversion from DN to db.[22]. After the preprocessing, Object based supervised classification were performed [23], [24], [25], [26], [27] to enhance the working efficiency with a result of good accuracy. After preprocessing, a relationship between satellites derived fire intensity and DEM slope has been derived with a strong negative trend in optical data and a poor negative trend with microwave data. Forest fire intensity map has been created to analyze the behavior of fire with slope intensity. A LULC map has been generated to analyze the pattern of fires regarding settlement areas or anthropogenicprone areas. LULC map has been classified into seven groups where flora regions are divided into three zones; agriculture, pasture and forest area to extract particular forest regions. As from the map it has been found that forest fire frequencies tend to increase with the interference of humans. After the LULC map, a fire damage assessment map is generated to carve out the specific fire prone areas over the forest regions. Trend analysis can be a good approach to understand the pattern of fire over the years. From fig 10, it can clearly interpret that comparing the frequency of fires in 2015, 2016, 2017, 2018 and 2019, the rate of forest fire is decreasing. Decreasing the number of forest fires may be the result of the government. policies to protect forests and awareness among humans to save the flora resources.

VI. Conclusion

The fusion data has become a very prominent tool to extract better resolution based maps of hilly regions. We can conclude that even forest fire pattern, behavior and trend can be assessed through optical data but the limitation of optical derived imagery in cloud and forest canopy penetration and clear weather condition dependency has increased the popularity of microwave data among researchers and scientists. Even though we cannot ignore the importance of optical data for thermal reflection analysis and land cover mapping. Forest fire analysis is important to understand the anthropogenic and climatic causes, patterns, behaviors and factors. Forests are very sensitive resources for humans. They not only provide oxygen but they are habitats for fauna, help to reduce soil erosion, and enhance the chances of rain as well. In hilly areas, forests are primary sources for livelihood in mountain rural areas. So its preservation is very important. With the help of forest fire assessment, government or agencies can plan better policies and methods to preserve the forests.

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Saumya Srivastava, et. al. “Forest Fire Damage Assessment using GIS in Uttarakhand – A case study.” *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 8(4), (2020): pp 51-60.