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INTEGRATING SPECTRAL INDICES, TOPOGRAPHIC FACTORS, AND FIELD DATA INTO DETECTING POST-FIRE BURN SEVERITY

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Abstract: *Forest fire has a wide range of long and short-term devastating and consequential impacts on the habitat and forest ecosystems. Topography is an important factor that influences fire patterns, its severity, and spatial distribution. The present study quantified forest severity (the consumption and reduction value of burnt forest vegetation) and assessed the relationship of forest severity with topographic factors and spectral indices computed using the Digital Elevation Model (DEM) and Landsat-8 imagery, respectively. The severity classes of forest fire identified were low, moderate, high and very high. The results showed that the reduction ratio of shrubs ranged from 100% to 16% and the reduction ratio of herbs ranged from 100% to 43% in the high and very low severity class, respectively. Similarly, litter and duff were reduced to 96% in the high severity class to 27% in the very low severity class. Regarding the consumption of burnt fuel, the highest and lowest litter burnt was 390 g/m*^{2} *and 40 g/m*^{2}*, respectively, whereas duff consumption ranged from 100 g/m*^{2} *to 34 g/m*^{2} *for the high and very low severity class, respectively. As far as correlation is concerned the elevation, heavy fuel, medium fuel, NDVI, NBR, and NBI were significantly correlated with fire severity class, while aspect relation was insignificant. Likewise stepwise regression showed that NBR, NDVI, and medium fuel entered in selection while other variables (elevation, aspect, heavy fuel, and BAI) were excluded. Overall, R*^{2} *for the stepwise regression model was 0.77, which means that 77% of fire severity was explained while 23% remained unexplained. The present study suggests that a more detailed insight study should be conducted by using high resolution DEM and satellite imagery in order to quantify the influence of topographic factors and forest density on fire severity.*

Key words: *forest fire, reduction ratio, severity, topographic variation.*

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1. Introduction

Forest fire is one of the main factors that change the structure of a forest [2]. Fire regime represents the combination of factors which include spatial design, frequency, intensity, seasonality, and size distribution over an extended period of time and space. Assessment of fire severity needs to be carried out before, during, and after an incident. Fire force is the physical ignition process by which energy discharges from organic matter while fire is associated with burn severity [26]. Forest fire has many socio-economic impacts causing forest loss, property loss of inhibitants, and in the worst cases, even human casualities [22]. Fire intensity can be divided in two components including fire downward infiltration into the soil and its upward exchange to vegetation and the environment [17]. The extent of fire severity can be estimated by investigating the percentage of dead material and reduction expressed by plant mortality and the percentage of reduction in loading (%) and consumption (kg/m^2) regarding fuel consumption [24], [36]. In most fire and burn severity assessments, the initial fire effect is implicit due to changes in aboveground shrubs and trees [15]. Large trees can regerminate after a forest fire and this can affect the fire assessment processes. It is important to mitigate damages caused by fire in order to manage new tree seedlings and other vegetation [9], [20], [25]. Moreover, evaluation of biological and physio-chemical effects of fire on the soils is also important [6], [24]. Remote sensing and field data used to evaluate the extent and magnitude of forest fire [16], [31] and the associated loss of flora and fauna and their habitat [17]. This information can be used to mitigate the losses due to forest fire and design a management plan which could help to avoid such events in future [30], [34]. Spectral unmixing and radiative transfer models are techniques that include remote sensing [4], [7], spectral mixture analysis [21, [35], and rationing band reflectance data [7], [17]. For a standard spectral index to assess the severity of a fire, the Normalized Burn Ratio (NBR) has become accepted and regularly used in the context of band rationing [28], [34]. By combining near-infrared (NIR) with short wave infrared (SWIR) reflectance, vegetation moisture content relates to NBR. A clear distinction between a burned and an unburned region is permitted by before and after fire ratio images which are often bi-temporally differenced, resulting in differenced layers [17]. The performance of different spectral indices is assessed in this study which includes the commonly used Normalized Difference Vegetation Index (NDVI), the Burned Area Index (BAI), and the Normalized Burned Ratio (NBR), etc. The relation between NDVI and forest density is fairly strong, which is why NDVI is a widely used index in ecological remote sensing. In order to reduce the influence of disturbing signals, many updates of NDVI have been proposed for better quality results. The mid-infrared (MIR) spectral region relies on the fact that the latter spectral domain is related to vegetation moisture content, although the MIR region remains largely unaltered by aerosols as compared to the red band. BAI is the index that focuses on the red-NIR feature space and is specially designed for post-fire effects applications [3]. BAI may be defined as calculation of bi-spectral distance from a pixel in the red-NIR region has the tendency to express fire areas and post fire analysis [3]. The SWIR and MIR regions are utilized in the computation of other burned land specific indices to detect post-fire changes because these regions have shown to be more detailed than those in the red region [23] and therefore, NBR shows parallel results to NDVI [17]. The main objectives of this study were (1) to quantify forest severity (the consumption and reduction value of burnt forest vegetation) and (2) to assess the relationship of forest severity with topographic factors and spectral indices computed using the Digital Elevation Model (DEM) and Landsat-8 imagery, respectively.

2. Materials and Methods

2.1. Study Area

This study has been carried out in the Lehtrar forest subdivision located in the lower regions of Rawalpindi, Pakistan in 2019 (Figure 1).

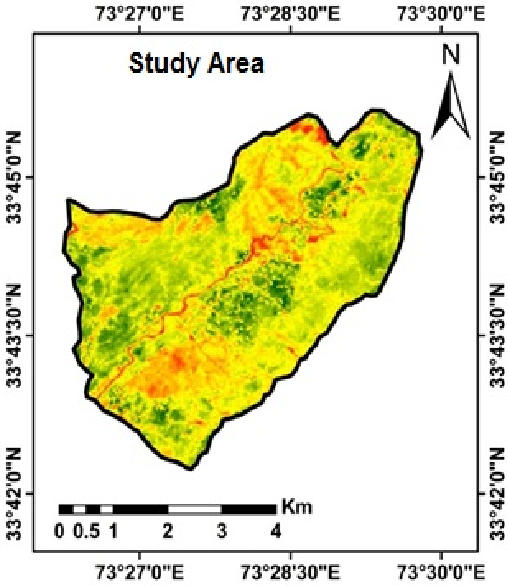

Fig. 1. *Study area map*

It is disjunctive territory limited to more protected gorges and Northern confronting inclines and an expansion of the Siwalik zone towards the east, encompassed by Karot valley, which drains in Jhelum River and also brings down Lehtrar valley in the Margallah Hills. The area has pleasant weather. The average precipitation ranges from 43 mm to 55 inches/year with snow fall up to 6 feet at higher altitudes. Lehtrar forest sub-division is subtropical Chir pine forest.

2.2. Methods

Throughout the surveys, sampling was carried out at different locations. The sampling locations were randomly selected covering all habitats, elevation, and other topographic features. The effect of topography on severity was categorized by patterns of vegetation damage and topographic factors (elevation, slope, aspects). The Digital elevation model (DEM) was used to identify low, moderate, high, very high, and extreme severity classes. At each burn site, tree and shrub structure, herbaceous cover along with elevation, slope and aspect were sampled with the help of DEM. The sampling design consisted of long parallel transect lines at each burn site from topographic factors spaced 50 m apart, at 5m intervals along each transect, a 10 m × 10 m plot was established for a total of 5 plots per site. The information used regarded the land use history of the burn sites, collected from maps and documents in the Forest Service records included data on fire location and date; other documentation about early fires was also used.

2.3. Data collection

For each station, three topographic variables were generated, namely elevation (m), slope (degrees), and aspect (degrees), using the spatial analyst tool ArcGIS 10.3. Perspective was changed over to an all-out factor characterizing angle as north (315–44 degrees), east (45–134 degrees), south (135–224 degrees), or west (225– 314 degrees). Rise and gradient estimations were created using the majority of the 10 × 10m cells inside the fire limits to portray its spatial distribution. Vegetation information was gathered at each station sampling protocols used in forest inventory using plot size (20 – 50m). Moreover, the cover and height of the tree stratum (all vegetation ≥5m) and bush stratum (all vegetation ≥0.5m and <5m) were assessed using five cover classes (0–5, 5–25, 25–50, 50–75, and 75–100%). Measurement at breast height (DBH) of trees in the tree layer was outwardly assessed. We additionally evaluated the height of the lower limit of the tree shade (for the most part >5m). Field measurements include the finding from the reduction ratio in percent and fuel consumption in each fire severity class (Table 1). The reduction ratio included the percent of burnt attributes, i.e., shrubs, herbs, litter, duff, and wood, while the consumption in kg/m^2 included the burnt weight of litter and duff (Table 2).

2.4. Remote Sensing

Landsat-8 imagery was acquired from USGS Earth Explorer for post-fire analysis. Landsat-8 was preprocessed before use for analysis in ENVI 5.3. The steps to rectify Landsat-8 imagery were (1) the conversion of radiance values to reflectance values, (2) IAR refection correction, (3) dark objects removal. Further, the rectified image was cropped by using a “subset” tool because it created only an area of interest in order to reduce time of computation. Also, Landsat-8 imagery was ready for spectral indices computation which includes vegetation index (NDVI) and burnt area indices (BAI and NBR). Moreover, field data of consumption and reduction value of forest vegetation burnt were overlaid on the NDVI, BAI, and NBR images. Masked pixels values were extracted and imported into excel sheet for further analysis. Similarly, DEM was used for elevation, aspect, and slope values at each field sample plot. Lastly, correlation and stepwise linear regression were developed among field data, topographic variables, and spectral indices.

3. Results and Discussion

3.1. Reduction Ratio and Fuel Consumption

The plot wise reduction ratios in percentage and fuel consumption for the “high” severity fire category are shown in Table 3. Regarding shrubs sampling in 3m from the plot center, the highest reduction ratio (94.5%) was found in Plot No. 5 while the lowest was estimated (37.5%) for Plot No. 3.

Table 1

Forest severity classes (1-5) in different compartments and field measurements

Fire severity Class	Substrate	Vegetation	Measurements
Unburned (1)	Not burned	Not burned	GPS Locations only
Very low (2)	Litter partially blackened Duff nearly unchanged Wood/leaf structures unchanged	Foliage burnt and attached to supporting twigs	Level-A
Low (3)	Litter burn to partially consumed, some leaf structure undamaged Surface is predominantly black; some gray ash may be present immediately Soil is not altered	Foliage and smaller twigs partially to completely consumed; branches mostly intact; less than 60% of the shrub canopy is commonly consumed	Level-A Level-B
Moderate (4)	Leaf litter consumed, leaving coarse, light colored ash Duff deeply burnt, but underlying mineral soil is not visibly altered Woody debris is mostly consumed Logs are deeply burnt, burned-out stump holes are common	Foliage, twigs, and small stems consumed; some branches (>0.6–1 cm in diameter) still present; 40–80% of the shrub canopy is commonly consumed	Level-A Level-B
High (5)	Leaf litter completely consumed, leaving a fine white ash All organic material is consumed in mineral soil to a depth of 1–2.5 cm, this is underlain by a zone of black organic material	All plant parts consumed leaving only base stem greater than 1 cm in diameter	Level-A Level-B

Fire effects (A-B) and measurements in the field Table 2

Selected fire effect	Measurement variable	Calculation	Description
Plant mortality (Level-A)	Percentage dead [%]	Trees ≥5.1 cm Diameter	Fire-caused overstorey tree mortality
		Trees ≤5 cm Diameter	Fire-caused understorey tree mortality
	Reduction in cover [%]	Shrubs	Shrub cover reduction
		Herbs	Herbaceous cover reduction
Fuel consumption (Level-B)	Reduction ratio [%]	Wood	Proportion woody fuel consumed
		Duff	Proportion duff fuel consumed
	Consumption [kg m^2]	Wood	Amount of woody fuel consumed
		Duff	Amount of duff fuel consumed

Almost all the herbs within 1m of the plot were burnt; the herbs in four out of five plots were completely burnt, which showed that the fire severity was high in these plots. Litter and duff were also reduced to great percentages; the highest litter reduction was observed in Plot No. 4 with 96% reduction, while the lowest reduction (76%) was recorded in Plot No. 3. Similarly, the highest and lowest reduction for duff was observed in Plots No. 1 and 2, respectively.

The percent of woody fuel burnt was determined as medium wood and heavy wood based on tree diameter range the range for the former was 3-20 cm and the latter 21 cm or larger, respectively. The highest reduction ratios (%) were 100 and 86, whereas the lowest reduction ratios were 76 and 66 for the medium and heavy woody class. The highest litter burnt was 390 g/m^2 while the lowest was 310 g/m^2. Throughout this study, the duff consumption was also almost similar. Also, plot wise reduction ratios in percentage and fuel consumption for the "moderate" severity fire category are shown in Table 3. The results revealed that the mean reduction ratio for shrubs was 69.5% and the highest and lowest were 100% and 20%, respectively. Regarding herbs, the mean reduction ratio was 85.7%, the highest was 100%, and the lowest was 50%. Litter and duff were also reduced to a great percent; the highest litter reduction was 100% while the lowest was 10%. Likewise, the highest and lowest reduction for duff 100% and 50%, respectively. The mean values for both litter and duff reduction were 88.2% and 77.2% respectively. The highest reduction ratios for the medium and heavy woody class were 88% and 77%, whereas the lowest reduction ratios were 20% and 10%, respectively. Regarding the consumption of burnt fuel, the highest litter burnt was 350 g/m^2, while the lowest 40 and 20 g/m^2 for litter and duff, respectively.

The plot wise reduction ratios and fuel consumption for the "low" severity fire category are shown in Table 4. The results indicate that the mean reduction ratio for shrubs was 50.4 % and the highest and lowest were 88% and 0%, respectively. Regarding herbs, the mean reduction ratio was 74.5%, the highest was 100%, and the lowest was 43%. The results showed that the highest litter reduction ratio was 100%, the lowest was 67% with the mean value of 84.8 %. Similarly, the highest and lowest reduction for duff was 98% and 44%, respectively. The highest reduction ratios for the medium and heavy woody class were 65% and 34%, whereas the lowest reduction ratios were 12% and 2%, respectively. Regarding the consumption of burnt fuel in the "low" severity class, the highest burnt weights were 400 and 300 g/m^2, while the lowest were 45 and 40 g/m^2 for litter and duff, respectively. Likewise, the results for the "very low" severity class showed that the mean reduction ratio for shrubs was 33.6%, and highest and lowest were 100% and 6%, respectively (Table 4). Regarding herbs, the mean reduction ratio was 90.8%, the highest was 100%, and the lowest was 67%. The highest litter reduction ratio was 100% and the lowest was 54% with the mean value of 87.1%. The highest and lowest reduction for duff was 98% and 27%, respectively. The highest reduction ratios for the medium and heavy woody class were 45% and 54%, whereas the lowest reduction ratios were 10% and 4%, respectively. Regarding "consumption" in g/m^2, the highest burnt weights were 200 and 500 g/m^2, while the lowest were 40 and 34 g/m^2 for litter and duff, respectively.

Table 3

Reduction ratio and consumption in kg/m^2 for “high” and “moderate” severity class

Plot No.	**Reduction ratio [%]**						**Consumption [kg/m^2]**			
	Shrubs	Herbs	Litter/ Humus	Duff	Wood medium	Wood heavy	Total weight (Litter)	Weight burnt (Litter)	Total weight (Duff)	Weight burnt (Duff)
“high” severity class										
1	87.5	100	83	100	100	80	120	110	150	150
2	65	100	89	80	80	85	250	230	250	160
3	37.5	100	76	87	76	66	400	380	400	380
4	92.5	100	96	99	98	80	200	180	300	280
5	94.5	100	95	89	90	86	400	390	400	390
6	70	96.15	85	95	80	70	350	310	350	300
“moderate” severity class										
1.	50	83	95	89	55	45	200	180	300	260
2.	50	100	95	90	65	22	100	90	100	89
3.	100	100	99	99	86	76	100	77	100	67
4.	80	100	88	90	80	77	200	180	200	180
5.	90	100	10	99	88	77	300	280	200	190
6.	50	71	78	70	65	32	200	160	200	160
7.	83	86	96	90	45	45	300	170	300	250
8.	69	67	78	87	65	45	100	98	100	87
9.	67	88	89	78	87	76	100	90	100	89
10.	83	91	99	67	56	44	400	280	400	340
11.	20	80	90	60	56	33	200	180	200	160
12.	53	50	80	89	56	33	100	90	100	80
13.	50	91	95	76	23	10	200	117	100	69
14.	90	80	95	77	67	50	400	300	400	350
15.	50	91	80	60	50	50	300	280	300	270
16.	93	100	99	90	45	30	200	110	200	100
17.	83	83	90	67	34	11	100	40	100	20
18.	67	100	88	50	40	20	350	270	300	150
19.	67	83	97	100	80	50	400	350	400	300
20.	60	83	95	78	67	55	100	80	100	70
21.	60	100	80	60	66	32	250	200	250	190
22.	67	67	90	70	43	22	100	70	100	60
23.	75	88	100	50	20	20	350	80	350	75
24.	90	80	100	71	44	23	200	70	200	65
25.	90	80	100	79	23	23	200	70	200	65

Table 4

Reduction ratio and consumption in kg/m^2 for "very low" severity class

Plot No.	**Reduction ratio [%]**						**Consumption [kg/m^2]**			
	Shrubs	Herbs	Litter/ Humus	Duff	Wood medium	Wood heavy	Total weight (Litter)	Weight burnt (Litter)	Total weight (Duff)	Weight burnt (Duff)
"low" severity class										
1.	50	63	100	60	40	20	300	250	300	180
2.	75	60	75	55	33	10	200	120	200	100
3.	40	71	74	78	45	34	300	120	200	110
4.	50	83	80	65	43	12	100	54	100	54
5.	50	63	89	78	56	34	300	150	200	100
6.	67	95	96	56	34	23	400	230	300	150
7.	45	56	95	88	34	23	350	300	300	200
8.	33	43	78	78	22	19	400	350	300	200
9.	53	83	89	98	34	25	300	240	250	250
10.	0	60	80	50	41	23	200	100	200	100
11.	88	71	70	89	56	34	400	350	300	300
12.	86	90	67	88	45	34	100	80	200	150
13.	40	83	99	77	65	33	400	400	300	260
14.	60	83	70	65	32	12	100	80	70	40
15.	33	60	67	78	45	34	300	160	300	160
16.	83	88	95	67	37	20	200	45	200	60
17.	67	100	100	80	34	12	300	200	300	200
18.	13	63	97	45	12	2	200	150	200	130
19.	25	100	90	44	22	12	300	150	300	140
"very low" severity class										
1.	27	90	54	40	10	5	100	60	100	40
2.	13	100	100	45	20	12	200	65	200	50
3.	18	94	90	45	23	12	200	70	200	500
4.	25	93	70	55	12	4	400	200	200	50
5.	17	91	95	65	32	12	200	180	200	170
6.	33	67	87	56	34	54	100	40	100	34
7.	77	93	95	27	20	13	100	50	100	80
8.	20	100	95	56	34	11	200	50	200	43
9.	6	93	95	98	45	23	200	100	200	50
10.	100	87	90	79	23	21	400	200	400	170

3.2. Topographic Variables and Spectral Indices

The plot topographic variables and spectral indices (NDVI, BAI, and NBR) are shown in Table 5. The results show that the mean elevation for the "high" severity class was 985 m with the highest and lowest elevations being 1,037 and 934m, respectively. The mean aspect degree was 284.35, the highest was 314, and the lowest was 262 degrees. As far as the spectral indices regarding, the highest value for the Normalized Difference

Vegetation Index (NDVI) was 0.9 and the lowest was 0.47 with the mean value of 0.67. Similarly, the highest and lowest values for the Normalized Burn Ratio (NBR) were 0.20 and 0.06, respectively, while the highest value for the Burn Area Index (BAI) was 0.36, with the lowest value 0.11. The mean value for BAI was 0.24. Also, plot wise details of topographic variables and spectral indices (NDVI, BAI, and NBR) for the “moderate” severity class are shown in Table 5. The results show that the mean elevation for the “moderate” severity class was 1,139 m with the highest and lowest elevation being 1,425 and 1,087m, respectively. The mean aspect degree was 290.15°, the highest was 347°, and the lowest was 10.5°. As far as the spectral indices regarding, the highest value for the Normalized Difference Vegetation Index (NDVI) was 0.81 and lowest was 0.34 with the mean value of 0.73. Likewise, the highest and lowest values for the Normalized Burn Ratio (NBR) were 0.21 and -0.03, respectively, while in the case of the Burn Area Index (BAI), the highest value was 0.39, and the lowest value was 0.10 with the mean value 0.28.

The plot wise details of topographic variables and spectral indices (NDVI, BAI, and NBR) for the “low” severity class are shown in Table 6. The results show that the mean elevation was 941 m with the highest and lowest elevations being 957 and 919m, respectively. The mean aspect degree was 276.59°, the highest was 347°, and the lowest was 194.5°. As far as the spectral indices regarding, the highest value for the Normalized Difference Vegetation Index (NDVI) was 0.97 and the lowest was 0.39, with the mean value of 0.71. Similarly, the highest and lowest values for the Normalized Burn Ratio (NBR) were 0.15 and 0.01, respectively, while in the case of the Burn Area Index (BAI), the highest value was 0.17 and the lowest value was -0.05 with the mean value of 0.05. As far as the “very low” severity class regarding, plot wise details of topographic variables and spectral indices (NDVI, BAI, and NBR) are shown in Table 6. The results show that the mean elevation was 887.6m with the highest and lowest elevations being 965 and 312m, respectively. The mean aspect degree was 223.11° with the highest being 345.4° and the lowest 4.18°. Concerning the spectral indices, the highest value for the Normalized Difference Vegetation Index (NDVI) was 0.79 and the lowest was 0.00 with the mean value of 0.51. Likewise, the highest and lowest values for the Normalized Burn Ratio (NBR) were 0.19 and -0.02, respectively, while in the case of the Burn Area Index (BAI), the highest value was 0.26 and the lowest value was 0.00 with the mean value of 0.127.

Table 5

Topographic variables and spectral indices for “high” and “moderate” severity class

Plot No.	**Elevation [m]**	**Aspect [degree]**	**NDVI**	**NBR**	**BAI**
“high” severity class					
1.	1,037	290.17	0.51	0.11	0.19
2.	1,023	262.05	0.47	0.14	0.20
3.	947	265.47	0.82	0.20	0.36
4.	934	273.36	0.81	0.20	0.36
5.	959	300.66	0.88	0.08	0.11
6.	1,012	314.35	0.90	0.06	0.23
“moderate” severity class					
1.	1,119	329.931	0.73	0.13	0.20
2.	1,132	332.745	0.76	0.18	0.36
3.	1,136	312.879	0.76	0.16	0.31
4.	1,156	293.199	0.81	0.17	0.33
5.	1,176	308.946	0.75	0.15	0.27
6.	1,171	311.121	0.75	0.15	0.27
7.	1,160	304.479	0.80	0.17	0.32
8.	1,152	310.764	0.81	0.17	0.33
9.	1,136	312.879	0.76	0.16	0.31
10.	1,132	332.745	0.76	0.18	0.36
11.	1,119	329.931	0.81	0.15	0.30
12.	1,119	329.931	0.73	0.13	0.20
13.	1,425	128.418	0.34	0.20	0.10
14.	1,126	318.468	0.77	0.21	0.36
15.	1,104	329.265	0.73	0.20	0.35
16.	1,100	336.615	0.77	0.17	0.27
17.	1,087	302.471	0.80	0.20	0.37
18.	1,098	288.435	0.73	0.21	0.39
19.	1,107	297.474	0.70	0.21	0.37
20.	1,109	277.595	0.75	0.19	0.31
21.	1,116	277.001	0.66	0.17	0.25
22.	1,126	263.367	0.74	-0.03	0.15
23.	1,123	267.581	0.70	0.12	0.22
24.	1,123	10.561	0.76	0.18	0.28
25.	1,132	347.005	0.81	0.06	0.13

Table 6

Topographic variables and spectral indices for “low” and “very low” severity class

Plot No.	**Elevation [m]**	**Aspect [degree]**	**NDVI**	**NBR**	**BAI**
1.	947	258.691	0.65	0.02	0.02
2.	940	240.524	0.65	0.02	0.02
3.	944	211.607	0.65	0.02	0.02
4.	939	218.293	0.97	0.02	-0.01
5.	939	218.293	0.97	0.02	-0.01
6.	937	194.534	0.77	0.08	0.11
7.	942	201.371	0.77	0.08	0.11
8.	943	298.618	0.95	0.04	0.13
9.	939	326.316	0.96	0.08	0.17
10.	942	347.005	0.56	0.15	0.10
11.	952	303.906	0.59	0.07	0.03
12.	957	275.856	0.77	0.06	0.10
13.	945	252.897	0.56	0.02	0.07
14.	950	317.497	0.39	0.08	0.01
15.	919	334.026	0.70	0.01	0.00
16.	944	333.741	0.73	0.07	0.10
17.	936	293.429	0.78	0.01	-0.05
18.	921	294.864	0.43	0.08	-0.01
19.	946	333.741	0.73	0.07	0.10
“very low” severity class					
1	947	4.1849	0.54	0.04	0.06
2	950	12.847	0.57	0.15	0.12
3	950	12.847	0.68	0.15	0.26
4	312	216.469	0.00	0.00	0.00
5	965	339.146	0.50	0.19	0.23
6	948	345.466	0.67	0.11	0.11
7	956	342.121	0.41	0.17	0.12
8	960	336.801	0.39	0.17	0.21
9	960	336.801	0.49	0.15	0.16
10	928	284.421	0.79	-0.02	0.00

3.3. Correlation and Stepwise Linear Regression

All the explanatory variables (topographic, spectral indices, and field data) were correlated with the fire severity classes. The elevation, heavy fuel, medium fuel, NDVI, NBR, and NBI were significantly correlated with fire severity class while aspect was insignificant (Table 7) because significance greater than 0.05 means larger p-value.

Table 7

Correlation between severity class, topographic variables, and spectral indices

	Fire severity	**Elevation**	**Aspect**	**Heavy fuel**	**Medium fuel**	**NDVI**	**NBR**	**BAI**
Fire severity	1	0.483^{**}	0.172	0.455^{**}	0.614^{**}	0.589^{**}	0.839^{**}	0.418^{**}
Elevation	0.483^{**}	1	0.110	0.178	0.228	0.530^{**}	0.550^{**}	0.224
Aspect	0.172	0.110	1	0.341^{**}	0.353^{**}	0.109	0.177	0.145
Heavy fuel	0.455^{**}	0.178	0.341^{**}	1	0.796^{**}	0.258^{*}	0.415^{**}	0.406^{**}
Medium fuel	0.614^{**}	0.228	0.353^{**}	0.796^{**}	1	0.356^{**}	0.532^{**}	0.420^{**}
NDVI	0.589^{**}	0.530^{**}	0.109	0.258^{*}	0.356^{**}	1	0.838^{**}	0-.085
NBR	0.839^{**}	0.550^{**}	0.177	0.415^{**}	0.532^{**}	0.838^{**}	1	0.271^{*}
NBI	0.418^{**}	0.224	0.145	0.406^{**}	0.420^{**}	-0.085	0.271^{*}	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Among the explanatory variables, NBR, NDVI, and medium fuel were entered in stepwise selection as these were significant with P-value lower than 0.05, while others (elevation, aspect, heavy fuel, and BAI) were excluded from stepwise selection as they were insignificant with P-value larger than 0.05 (Table 8). The overall R^2 for the stepwise regression model was 0.774 which was similar to that of the multiple linear models.

Table 8

Stepwise linear regression severity class, topographic variables, and spectral indices

Variables entered	**Variables removed**		**Sig**	**Regression summary**	
NBR			0.000	R	0.880
NDVI			0.008	R Square	0.774
Medium			0.014	Adjusted R Square	0.762
	Elevation		0.286	Std. Error	0.468
	Aspect		0.515	F-value	63.909
	Heavy		0.386	Sig	0.000
	BAI		0.450		
Model description					
	Unstandardized coefficients		Standardized coefficients	t	Sig
(Constant)	1.006	0.161		6.263	0.000
NBR	7.428	0.964	1.010	7.708	0.000
NDVI	-4.419	1.608	-0.326	-2.748	0.008
Medium	0.008	0.003	0.193	2.525	0.014
Model equation Fire Severity = 7.428*NBR+-4.419*NDVI+0.008*MediumFuel+1.006					
Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).					

4. Discussion

The results included the findings from the reduction ratio in percent and fuel consumption in each fire severity class. The reduction ratio includes the percent of burnt attributes, i.e. shrubs, herbs, litter, duff, and wood, while the consumption in kg/m^2 includes the burnt weight of litter and duff, the reduction ratio [5] and vegetation consumption of fire patterns and severity of distinct classes [29]. Moreover, topographic variables such as elevation and aspect and Landsat-8 spectral burnt indices which include NDVI, BAI, and NBR were computed for the sampled sites [32]. The principal results of forest fire and severity occurred due to anthropogenic activities as well as sparking, and natural causes and their impact have been broadly discussed [11], [27], [32]. Dominant grasses, herbs, and shrubs compete via extended canopy shading and better resistance to the direct consequences of forest fire patterns and severity. Therefore, frequently burned sites have high regeneration ratio. Reduction ratios in percentage and fuel consumption for the "high" severity fire category were high. Regarding shrubs sampling in 3m from the plot center, the highest reduction ratio was 94.5%, while the lowest was 37.5%, which was consistent with the findings of Collins et al. [5], who reported similar fuel consumption for "high" severity fire. Almost all the herbs within 1m were burnt; herbs in four out of five plots were completely burnt, which shows that the fire severity was high in these plots. However, within 2m all herbs and shrubs were burnt; herbs in 6 out of 7 plots were completely burnt, which shows severity and fire patterns of high class [1], [11]. Litter and duff were also reduced to a great percent; the highest litter reduction was observed with 96% reduction, while the lowest was 76%. Similarly, Veblen [33] reported that litter and duff were reduced to high level percentage; the highest litter reduction was 92.6% and the lowest was 88.78%. The percentage of woody fuel burnt was determined as medium woody and heavy wood based on tree diameter range; the range for the former was 3-20cm and for the latter was 21cm or larger. The highest reduction ratios were 100% and 86%, whereas the lowest reduction ratios were 76% and 66% for the medium and heavy woody class. In another study, Veblen [33] reported that fire severity of medium and high classes were observed as the higher diameter trees (above 20cm) caught fire which accelerate intensity of fire as well. Likewise, the highest reduction ratios were 90 and 96% for heavy severity whereas the lowest reduction ratios were 66 and 64% for the medium fire severity class.

This is because of preferential burning of vegetation, which reduces the above-ground biomass of dominant forest trees and increases light availability for different species of chir pine [13], [14], [19]. Therefore, common fire and grazing have opposite effects on aid availability such that when blended, light and N availability increase and consequently species richness increases [5]. Topographic variations may cause intense fire and influence fire pattern which destroys regeneration and ground vegetation (undergrowth). This indicates that grazing is the main driver of plant community composition and dynamics, and its effects are mediated to some degree through soil type. For instance, cover of woody species has good density at higher slope soils than on lowland soils. Moreover, it has also been observed that surface fires are less severe and caused less damage to forest cover as compared to big crown fires that go away few survivors over regions of many hectares. These results are consistent with different researches that display that subalpine wooded area structure in the southern Rockies is normally formed by way of rare stand-changing fires in preference to through surface fires [8], [18]. Topography has been empirically proven to strongly influence vegetation type and density [10].

5. Conclusion

Forest fire has a wide range of long and short-term devastating and consequential impacts on the habitat and forest ecosystems. It is caused by both man-made and natural factors. The main natural factors are fuel, topography, climatic, and meteorological conditions. Forest fire and severity in the dry sub expanses are becoming superior and extra precise. The most significant query might be that topographic variations have a influence on the fire patterns and severity. The influence of topographic fluctuation on severity and patterns of fire resulted as a consequence of core researched, which provided the explanation of how and why topographic influence on fire patterns and severity and its intensity affect ecosystems, as well as species particularly following fires and severity, whereas straight data on fire intensity and severity are missed and impact casually fluctuates among and between distinct forest structures. Intense fire patterns are greatly linked with forest density and area and also wind direction may cause serious consequences in case of intense fire. After a forest fire, carbon sequestration capacity of the forest was severely decreased along with numerous supplementary environmental functions. Topographic variations influence severity as well as fire patterns in a way that fire patterns go in different ways taking some important basic things in account like different aspects. Prescribed burning as well as some other techniques are required to overcome forest fire and to enhance forest structure and density. Due to forest fire, young seedlings are found to be susceptible. Aspect has a greater role in forest fire and severity. We have observed that on northern slopes, fire causes less damage to forest structure and vegetation as compared with the southern aspect when taking slope into account, which does not have a large role. However, temperature and weather conditions greatly affect the structure and spreading of fire. Prescribed burning can help to overcome such problems. Distinct methodologies should be implemented before fire seasons so they cover such damages. From this research, it is evident that due to topographic variations, forest fire and severity create greater loss to regeneration and forest trees, taking the weather and climatic conditions. Current research highlights a greater loss in vegetation structure and regeneration.

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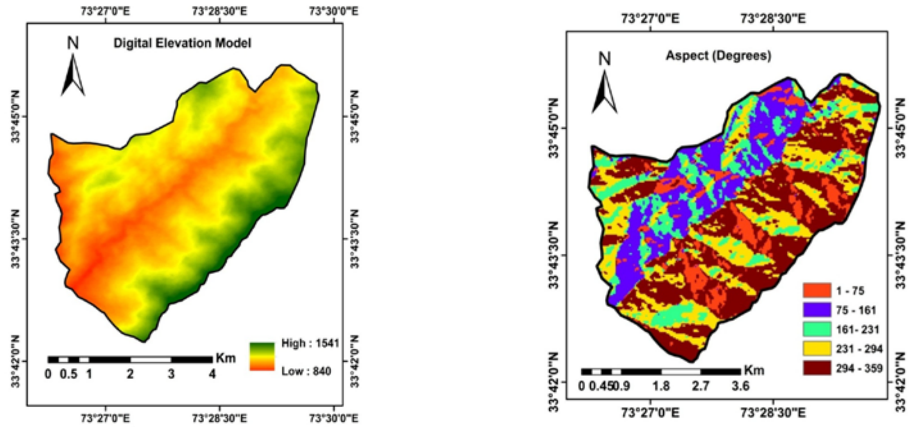
Annex I. *Topographic factors computed from DEM*



Annex II. *Spectral Indices computed from Landsat-8 imagery*