

Long Term Monitoring of Forest Fires in Silent Valley National Park, Western Ghats, India Using Remote Sensing Data

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Abstract The main objective of this study is to integrate satellite derived forest burnt areas over a multi-decadal scale to understand fire frequencies in Silent Valley National Park, Kerala, India. There are nine vegetation types distinguished i.e. wet evergreen forest, shola, semi evergreen forest, moist deciduous forest, dry deciduous forest, savannah, reed brakes, scrub and grasslands using Resourcesat-2 LISS III data. The spatial extent of burnt area found to be highly varying and has been estimated as 7.95 km² in 1973, 17.19 km² in 1985, 5.51 km² in 1989, 9.55 km² in 1990, 4.55 km² in 1994, 6.89 km² in 1996 and 5.80 km² in 1999. Analysis of burnt area coverage for recent decade based on 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013 and 2014 reveals fire affected area as 8.10, 4.20, 12.21, 5.52, 3.19, 0.62, 1.81, 2.03, 3.00 and 1.36 km² area respectively. Spatial analysis indicates, an area of 47.51 km² (19.5 % of total vegetation cover) affected by varying frequencies of fires from 1973 to 2014. High frequencies of fires have been observed in dry deciduous forests and grasslands. Buffer zone of national park has undergone frequent fires which may degrade climax forest vegetation and affects the regeneration and adaptability of indigenous species. Spatial tracking reveals 58.1 % grid cells were affected by forest fires. Overall, there is a declining trend of forest fires indicates management effectiveness in Silent Valley National Park.

Keywords Forest fire · Remote sensing · Silent valley · Conservation · Western Ghats

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Introduction

Land use change and fires are recognized as major drivers of the global change in terrestrial ecosystems (Rudel et al. 2005; Fraterrigo et al. 2006). Fires have influence on forest stand and landscape structural diversity (Weatherspoon and Skinner 1995). Fire is a key factor that determines the diversity and dynamics of vegetation (Bajocco et al. 2010). Understanding historical patterns of forest fires is important for ecological and forest managerial applications (Iniguez et al. 2008). While, most of the research studies have focused on deforestation, as compared to forest fires (Sanchez-Azofeifa et al. 1999). The Protected areas are often not subjected to deforestation, the major threat to biodiversity is due to forest fires and biological invasion which are interdependent (Hiremath and Sundaram 2005). There is a necessity of effective conservation strategy to expand the present Protected Area network in India (CBD 2004). Extended drought together with intensifying use of tropical forest has resulted in increase of forest fires (FAO 2007). Forest fire monitoring and mitigation became major management activities. However, there is no spatial database on different dimensions of forest fire in Protected Areas of India. The knowledge about the forest fires in India has been reviewed by Joseph et al. (2009).

Conventional methods of fire protection aided with information given by remotely sensed data are capable of addressing the problem with good technical strength (NRSA 2006). Several satellite based sensors like AWiFS, LISS-III, ETM⁺, SPOT, AATSR, AVHRR and MODIS have been used in forest fire detection and monitoring (Chand et al. 2006). Studies conducted in few protected areas of India have reported significant area under forest fires. The study in Mudumalai sanctuary recorded 30 % (1996–97) of forest burnt area (Kodandapani et al. 2004) followed by 26 % (2005) in Bandipur national park (Somashekar et al. 2009), 22 %

(2009) in Nagarjunasagar Srisailem tiger reserve (Reddy et al. 2012). The decadal time scale (2004–2013) study in Similipal biosphere reserve has reported 11.5 to 27.8 % of forests were affected by fires annually (Saranya et al. 2014).

Forest fire is a significant conservation threat to Silent Valley National Park, Western Ghats. Annual fire management plans are prepared and implemented with the involvement of local people by Kerala Forests and Wildlife Department. Despite the efforts for fire protection through participatory initiatives, there have been incidences of fire (KFWD 2012). In view of the conservation significance of the Silent Valley National Park, the present work have been taken for mapping of spatial extent of vegetation cover types and fire patterns using a multi time series satellite data and geospatial techniques.

Study Area

Silent Valley is a biological paradise of India. The evolutionary age of the Silent Valley evergreen rain forest is believed to be more than 50 million years (Swaminathan 1999). It is situated in the Palakkad district of Kerala state between latitude $11^{\circ} 2'$ and $11^{\circ} 14'$ N and longitude $76^{\circ} 20'$ and $76^{\circ} 32'$ E. Silent Valley was declared as a National Park in 1984 and made a part of the Nilgiri Biosphere Reserve during 1986. The total geographical area of Silent valley national park is

distributed under core zone (89.52 km^2) and buffer zone (176.88 km^2). It represents various vegetation types such as wet evergreen, shola, semi-evergreen, moist deciduous, dry deciduous, savannah, scrub and grasslands (Champion and Seth 1968). The forests of Silent Valley are characterised by high degree of endemism, as well as floral and faunal diversity. Several new taxa of flora and fauna have been described from the Silent Valley. During summer, heavy rains are the distinct characteristic of Silent Valley. South-west and north-east monsoons bring plenty of rain to this area. The annual mean temperature ranges from 9 to 38°C (Mathew et al. 2000). Blackish and slightly acidic soils are found in evergreen forests. The granite is the primary rock in the area with schists and gneiss, which give rise to the loamy laterite soils on slopes (Unnikrishnan 1989) (Fig. 1).

Materials and Methods

Spatial boundary of National Park was obtained from Kerala Forests and Wildlife Department. Multi-season Resourcesat-2 LISS III data of 2012 was used for vegetation type mapping. Visual image interpretation technique was used to prepare vegetation type map at 1:50,000 scale. The vegetation types and land cover were mapped on the basis of visual key elements and phenological pattern. Classification scheme of

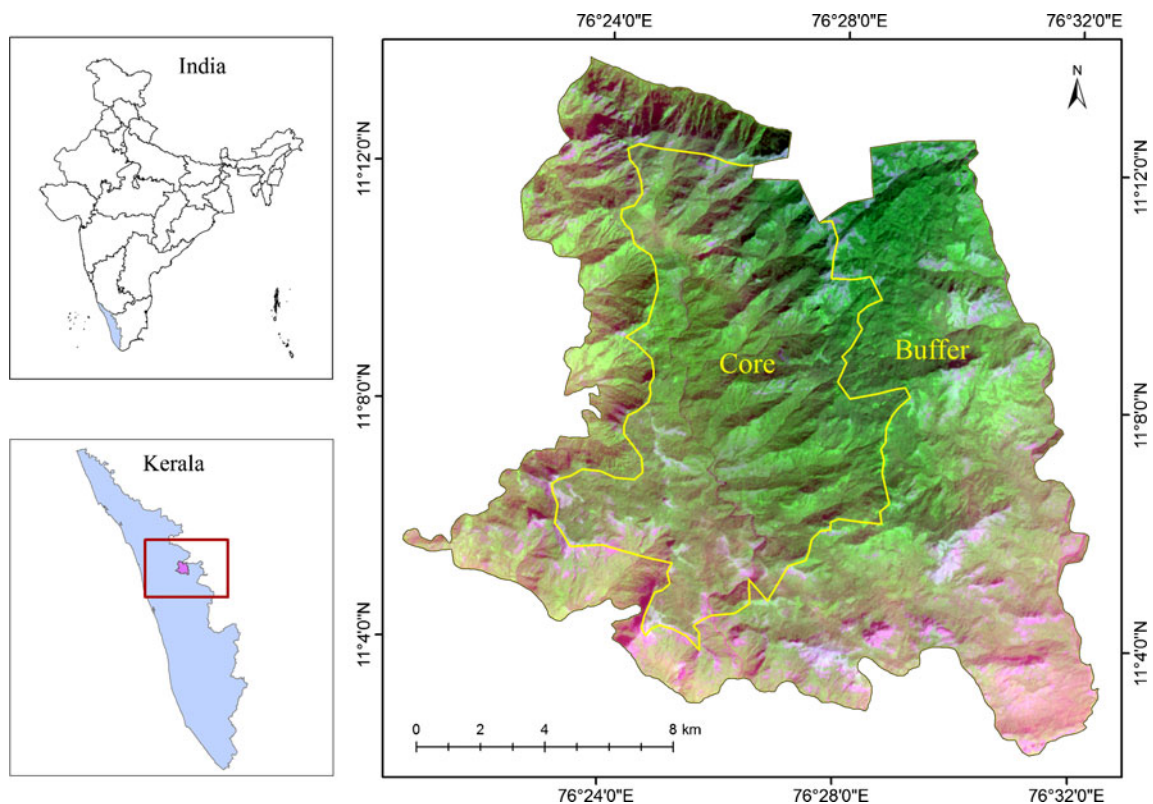


Fig. 1 Location map of Silent Valley National Park in Kerala, India

Champion and Seth (1968) have been followed in delineation of vegetation types. Multi-temporal dry season satellite data of Landsat MSS (1973, 1985), Landsat TM (1989), IRS 1A LISS I (1989, 1990, 1994), IRS 1B LISS I (1996), IRS 1C LISS III (1999), IRS P6 LISS III (2006), IRS P6 AWiFS (2005, 2006, 2007, 2008, 2009, 2010, 2011), Resourcesat-2 LISS III (2012) and Resourcesat-2 AWiFS (2012, 2013 and 2014) were used in the quantification of forest burnt area. Forest burnt area was extracted using hybrid classification techniques. The spatial extent of burnt area has been evaluated across natural vegetation types. To analyse impact of roads and settlements on fires, we have generated three categories of spatial buffers (100 m, 200 m and 500 m). These spatial buffer layers have been intersected with cumulative burnt area. The mean annual temperature and rainfall data have been downloaded from www.worldclim.com. SRTM Digital Elevation Model was used to understand implication of topography on distribution of fires (Rabus et al. 2003). All the classified burnt area maps were overlaid in 1 km × 1 km grid cells to get fire frequency over the 17 years representing four decades. Accuracy assessment was carried out for the forest burnt area map of 2014.

Table 1 Areal extent of Vegetation cover types and land use in Silent Valley National Park

Sl.no	Class	Area (km ²)	% Area
I	Forest		
1	Wet Evergreen	137.30	51.5
2	Shola	2.10	0.8
3	Semi Evergreen	39.70	14.9
4	Moist Deciduous	17.40	6.5
5	Dry Deciduous	21.90	8.2
	Sub total	218.40	81.9
II	Non forest		
6	Savannah	6.00	2.3
7	Reed Brakes	1.00	0.4
8	Scrub	3.80	1.4
9	Grassland	14.10	5.3
10	Barren	4.45	1.7
11	Water	1.50	0.6
12	Plantations	16.80	6.3
13	Agriculture	0.40	0.2
14	Settlements	0.07	0.0
	Sub total	48.12	18.1
	Grand Total	266.52	100

Results and Discussion

Vegetation Types

Natural vegetation cover occupies about 91.3 % of geographical area of Silent Valley National Park (Fig. 2). The forest constitutes 81.9 % of total geographical area, while the grassland, savannah, scrub, reed brakes covered 5.3 %, 2.3 %, 1.4 %, 0.4 % of area respectively (Fig. 2, Table 1). The classification of vegetation types shows five forest types i.e. Wet

evergreen forest (West coast tropical evergreen forest 1A/C-4, Nilgiri subtropical hill forest 8A/ C-1), Shola forest (Southern montane wet temperate forest 11A/C-1), semi evergreen forest (West coast semi evergreen forest 2A/C-2), moist deciduous forest (Southern moist mixed deciduous forest 3B/C-2) and dry deciduous forests (Southern tropical dry deciduous forest 5A/C-1); two degradation stages - savannah (South Indian tropical hill savannah woodland (8A/ C₁/ DS₁), reed brakes

Fig. 2 Vegetation types and land use of Silent Valley National Park

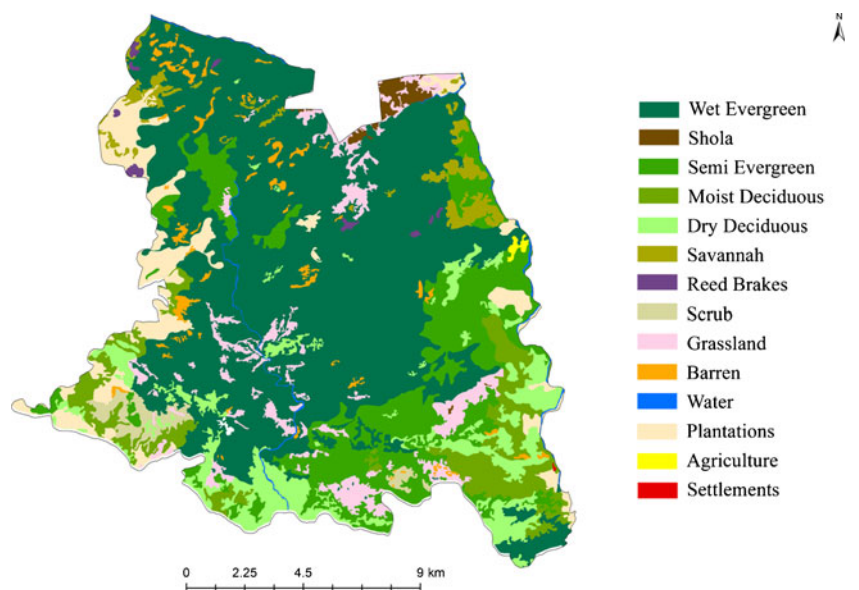


Fig. 3 Spatial maps showing distribution of forest burnt area

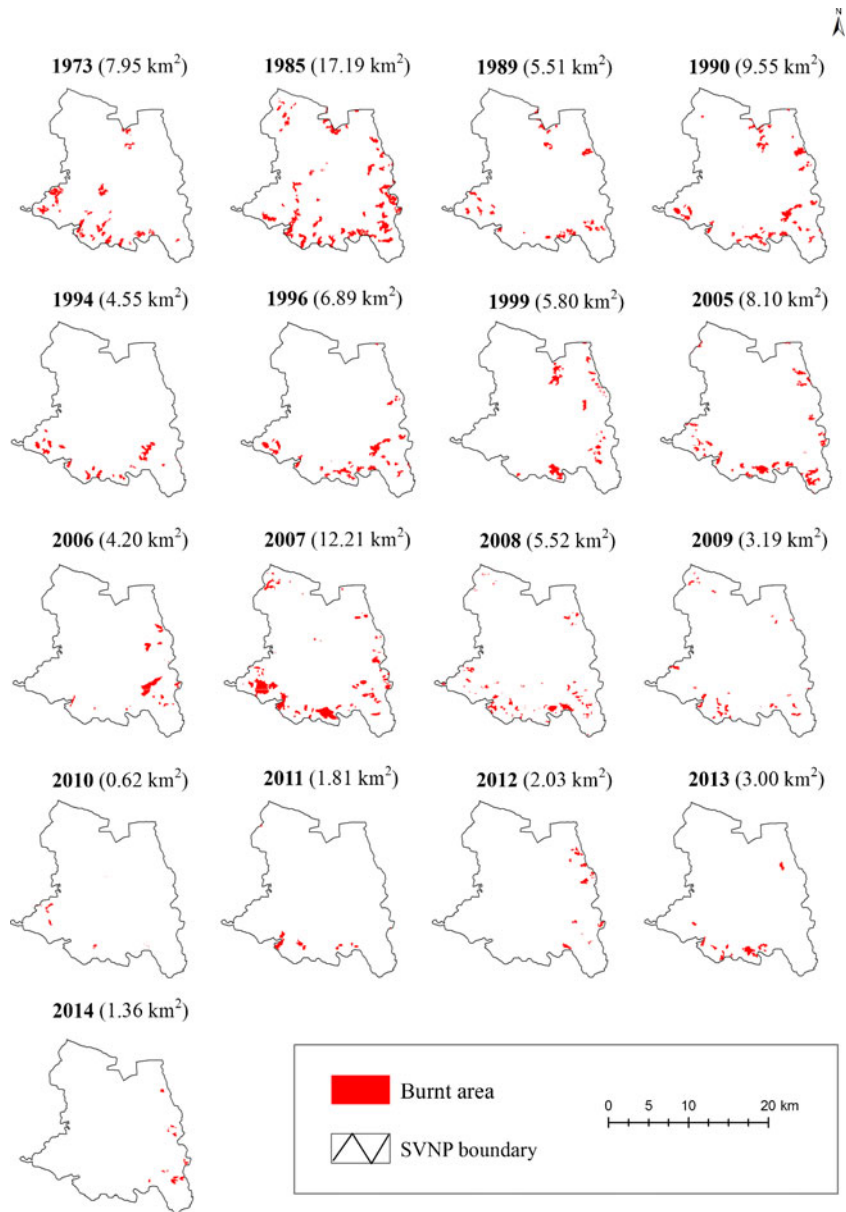
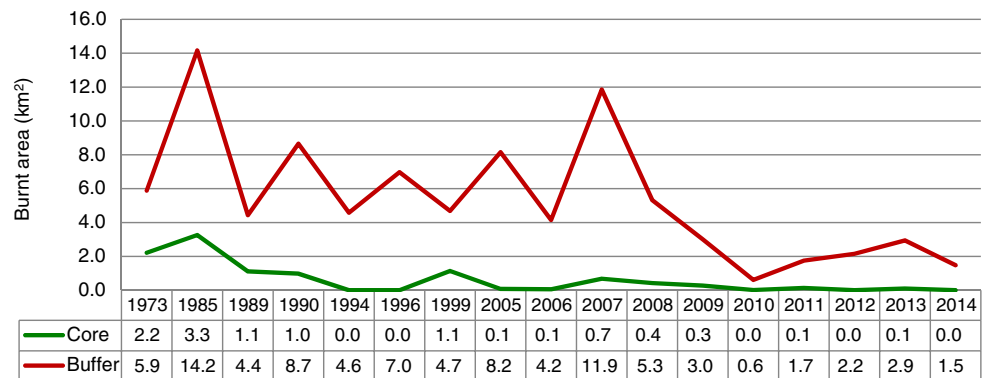


Fig. 4 Areal extent of burnt area patterns in different years



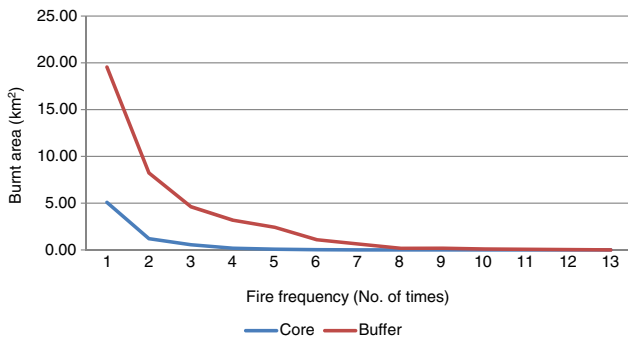


Fig. 5 Fire frequency across the core and buffer zones

(reed brakes 8A/C₁/E₁), one edaphic and climatic climax-scrub (Southern montane wet scrub IIA/ C₁/ DS₁) and grasslands (Southern montane wet grasslands IIA/ C₁/ DS₂) (Champion and Seth 1968). Wet evergreen forest is the predominant vegetation type occupies an area of 137.3 km² (51.5 % of total geographical area). In this top storey was dominated by *Cullenia exarillata*, *Palaquium ellipticum*, *Elaeocarpus munronii*, *Calophyllum elatum*, *Dysoxylum malabaricum*. Semi evergreen is the second predominant type occupies an area of 39.7 km² (14.9 %), the top canopy dominated by *Mesua ferrea*, *Sterculia guttata*, *Haldina cordifolia*, *Cedrela toona*, *Bischofia javanica*, *Schleichera oleosa*. The moist deciduous forest occupies an area of 17.4 km² (6.5 %) followed by dry deciduous forest with an area of 21.9 km² (8.2 %) (Table 1). Shola forests are distinctive vegetation mosaics and always associated with grasslands. The predominant trees of shola are *Ternstroemia gymnanthera*,

Gordonia obtusa, *Ilex wightiana*, *Rhododendron nilagiricum*, *Eugenia calophyllifolia*. The common species in grasslands are *Themeda* spp, *Dichanthium* spp, *Eragrostis nigra*, *Ischaemum pilosum*, *Cymbopogon polyneuros* (KFWD 2012).

Trends in Forest Burnt Area

The total burnt area has been estimated as 7.95 km² in 1973, 17.19 km² in 1985, 5.51 km² in 1989, 9.55 km² in 1990, 4.55 km² in 1994, 6.89 km² in 1996 and 5.80 km² in 1999. Quantification of the decadal trends based on 2005, 2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014 reveals burnt area as 8.10, 4.20, 12.21, 5.52, 3.19, 0.62, 1.81, 2.03, 3.00 and 1.36 km² area respectively (Fig. 3). Kerala Forests and Wildlife Department has recorded forest burnt area as 0.59 km² in 2007–08, 0.91 km² in 2008–09, 0.07 km² in 2009–10, and 0.05 km² in 2010–11 (KFWD 2012).

Zone Wise Analysis of Fire Frequencies

In the core zone, wet evergreen forest is the major type spatially covers an area of 76.34 km² (84.4 % of total vegetation cover in core zone). Semi evergreen forest is predominant vegetation type with area of 91.57 km² (60.11 %) in the buffer zone. Forest burnt area in the buffer zone varies between 0.6 and 11 km² (Fig. 4). Fire frequency analyses clearly indicate that burnt areas were low in the core zone, due to dominance

Table 2 The percentage of vegetation type area affected by fires (1973–2014)

Year	Semi Evergreen	Moist Deciduous	Dry Deciduous	Savannah	Reed Brakes	Scrub	Grassland
1973	3.79	5.06	14.85	0	0	18.81	11.28
1985	12.47	14.82	22.14	12.49	0.11	22.68	22.67
1989	3.59	2.62	5.51	9.85	0	17.22	8.33
1990	7.95	8.12	14.98	14.05	76.45	0	0.76
1994	1.75	2.82	5.95	0	0	25	7.82
1996	4.38	6.08	5.56	0	0	19.65	15.07
1999	2.96	1.9	6.06	10.17	0	0	16.7
2005	3.82	3.18	14.25	12.81	0	18.29	10.18
2006	1.66	0.24	6.26	6.38	0	0.52	12.23
2007	8.56	5.3	13.02	9.73	0	51.62	17.59
2008	2.54	2.58	9.32	5.27	0	18.68	7.03
2009	2.57	1.69	7.09	0.95	0	1.69	1.46
2010	0.13	0.6	1.35	0	0	3.7	0.16
2011	1.28	0.01	4.7	1.13	0	1.59	1.01
2012	1.37	0.3	2.24	10.52	0	0	2.19
2013	0.85	0.01	4.32	5.07	0	8.57	7.68
2014	0.74	1.19	3.04	2.26	0	0	0.4

Fig. 6 Temporal pattern of burnt area in fire prone vegetation types

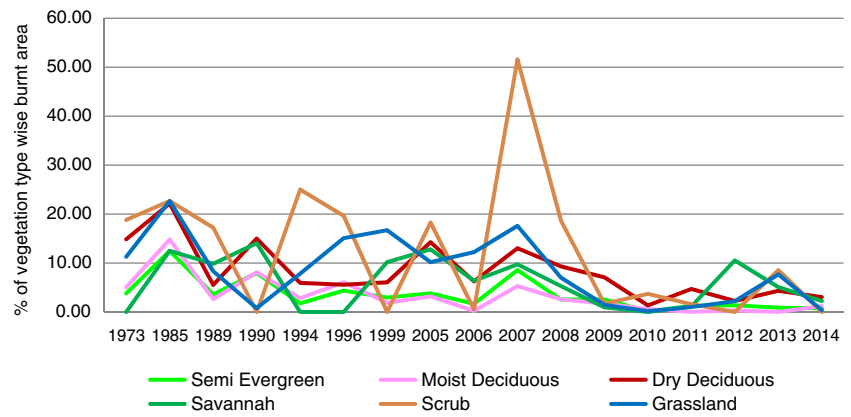
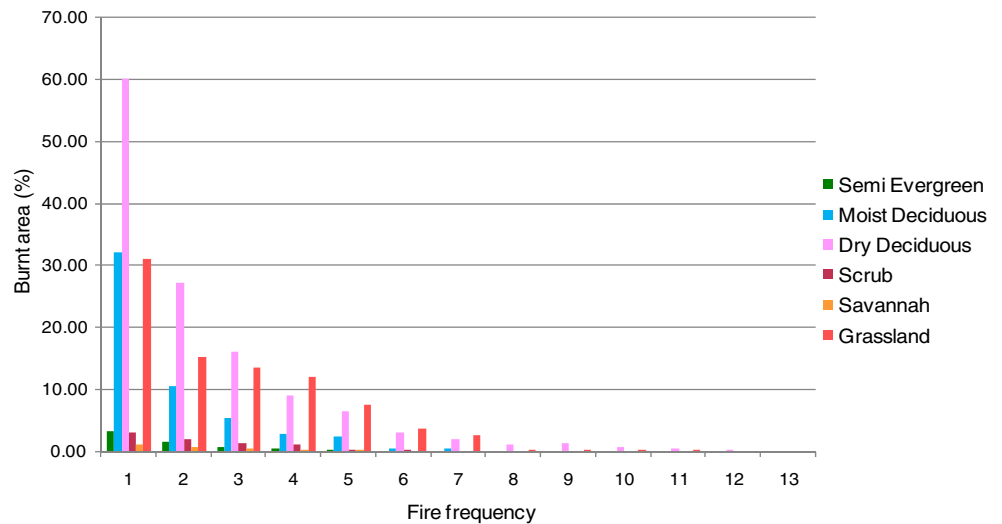


Fig. 7 Fire frequency across vegetation types



of wet evergreen forests, intactness and stringent conservation measures. The buffer zone shows significantly higher fire frequencies due to ease of access and anthropogenic interventions (Fig. 5). In the buffer zone, fires have been a regular anthropogenic factor accelerating degradation of natural climax forest vegetation and preventing regeneration. Most of the buffer area especially towards the western region has been severely damaged by fires. In the past, there had been extensive extraction of bamboo and reeds from various areas in the buffer zone (KFWD 2012). Due to the protection activities

after declaration as National Park there has not been any instance of fire inside the core zone for the past few years (KFWD 2012).

Distribution of Burnt Area Across the Vegetation Types

Fires were detected in six natural vegetation types. The proportion of total burnt area among the vegetation types for different years is presented in Table 2. Wet evergreen and shola forests are remain protected from fires due to high

Table 3 Forest fire frequency across the rainfall zones (area in km²)

Rainfall zone/ Fire frequency	1	2	3	4	5	6	7	8	9	10	11	12	13
2100–2500 mm	12.46	4.65	2.55	1.44	1.11	0.48	0.31	0.02	0	0	0	0	0
2500–2900 mm	11.78	4.36	2.2	1.8	1.37	0.63	0.32	0.16	0	0	0	0	0
2900–3100 mm	0.87	0.43	0.44	0.12	0.01	0	0	0	0	0	0	0	0

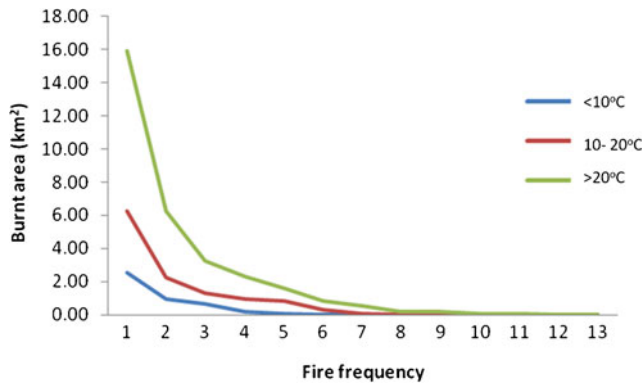


Fig. 8 Forest fire frequency across mean annual temperature zones

content of soil moisture, lush green cover and predominance of broad leaved trees. Fires were observed in the vicinity of shola and mainly concentrated in grasslands. A low density of burnt area patches were detected in the borders to the inner part of semi-evergreen and moist deciduous forests which are located at the edge of the grasslands, savannah and dry deciduous forests. Scrub, grasslands and dry deciduous forests had shown significantly high area under fires due to flammability (Fig. 6). Spatial overlay analysis across vegetation types indicates high frequency of fires under dry deciduous forests followed by grasslands (Fig. 7).

Accuracy analysis was performed on the classified forest burnt area map of 2014. GPS based 20 fire locations were used in assessing accuracy. Overall classification accuracy of 93.3 % and Kappa statistic of 0.92 was achieved. Validation of burnt areas of 1973–2013 was done based on the forest burnt area map of 2014.

Influence of Topography, Climate, Roads and Settlements

Topographic factors and climatic conditions affects fuel moisture, thus flammability (Schroeder and Buck 1970; Rothermel 1983). The overlay analysis for burnt area confirms the varying spatial distribution of fires. Analysis of implication of mean annual rainfall indicates high burnt area in rainfall zone of 2100–2500 mm

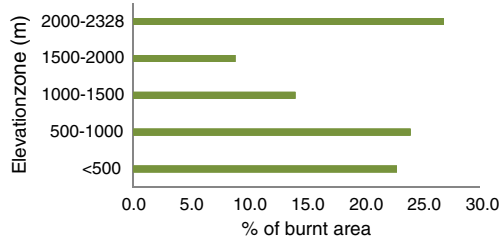


Fig. 9 Cumulative burnt area (1973–2014) distributed across elevation zones

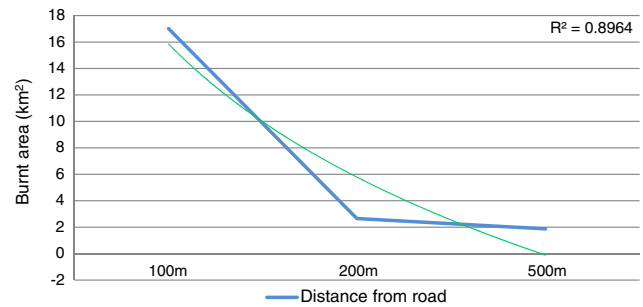


Fig. 10 Relationship between distribution of forest fires in relation to distance from roads

followed by 2500–2900 mm (Table 3). Analysis of spatial correlation between mean annual temperature zones is given in Fig. 8. The present analysis shows that fire prone areas are distributed randomly across the elevation zones (Fig. 9).

Roads and settlements inside forests play a major role in anthropogenic disturbances. Roads facilitate easy accessibility and endorse regional, local footprints of fires and other disturbances (Laurance et al. 2014). The study in Rajasthan observed that mostly fires were concentrated at the edge of the forest up to a distance of 500 m (Harikrishna and Reddy 2012). The present study also confirm that there a significant influence of roads and settlements on fire incidences. The burnt area within 100 m buffer of roads was estimated as 17 km² (79.03 %) followed by 3 km² (12.31 %) in 200 m buffer and 2 km² (8.67 %) in 500 m buffer (Fig. 10). The burnt area within 100 m buffer of settlements was estimated as 1.9 km² (45.2 %) followed by 1.8 km² (42.9 %) in 200 m buffer and 0.5 km² (11.9 %) in 500 m buffer.

Spatio-Temporal Pattern of Forest Burnt Area

Geospatial overlay analysis indicates, an area of 47.51 km² (19.5 % of total vegetation cover) affected by fires during 1973–2014. Temporal pattern of forest burnt area distribution in Silent Valley National Park shows burnt area affected for

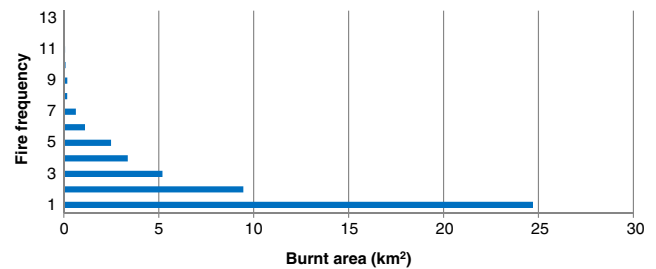
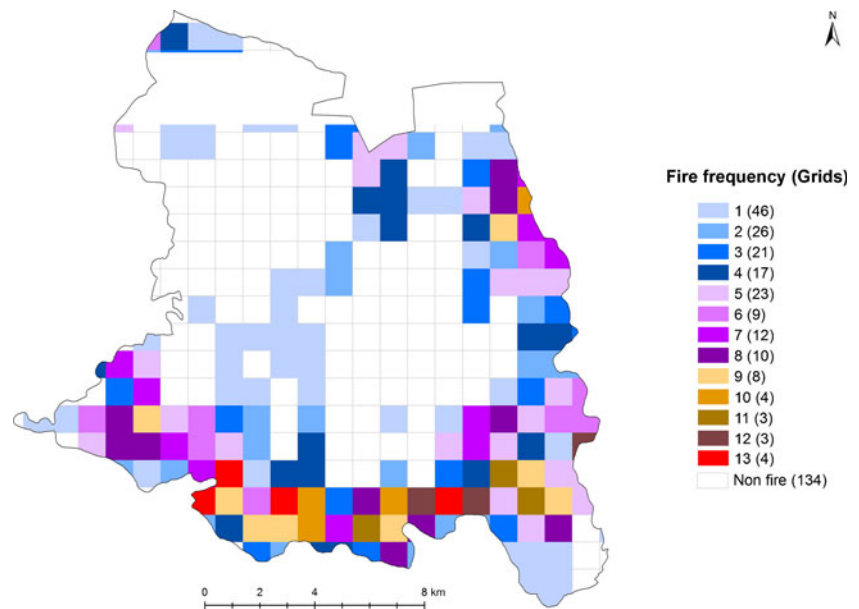


Fig. 11 Spatio-temporal pattern of forest fire frequency (No. of times) in the study area

Fig. 12 Spatial map of forest fire frequency in Silent Valley National Park



one time period as 24.7 km² (52.1 % of total burnt area), followed by 9.45 km² (2 times), 5.2 km² (3 times), 3.3 km² (4 times), 2.5 km² (5 times), 1.1 km² (6 times), 0.6 km² (7 times), 0.2 km² (8 and 9 times), 0.1 km² (10 and 11 times). It is evident from analysis that before declaration of Silent Valley National Park there was more fires. Historical observations have been proven that there was declining trend of fires as evidenced in terms of burnt area. The areas affected by fires more than 5 times have been estimated as 4.8 % of burnt areas. Hence, it is evident that the current management of Silent Valley National Park has been implementing stringent conservation measures. Graph representing the forest burnt area distribution has been presented in Fig. 11.

Grid Cell Wise Analysis of Fire Frequency

Spatial tracking through grid cell approach represents varying fire frequency in the study area (Fig. 12). There are total 320 grids (each 1 km²) recognized in Silent Valley National Park. Of these, 186 (58.1 %) grid cells were affected and 134 (41.8 %) grid cells are not affected by fires. Grid cell wise analysis shows that one to four times effected grid cells are 110 followed by five to eight times affected grids (54 grids) and more than eight times affected grids (22).

Management strategies, people attitude and local conditions are correlated with conservation effectiveness of protected areas. Evaluating the conservation effectiveness is becoming a common practice to improve management outcomes (Cook et al. 2014). The Silent Valley management has succeeded to prevent deforestation due to the effective protection activities with people participation after declaration as National Park (Satish et al. 2014).

Conclusions

To prevent forest fires the management has made a special attention and conducting awareness programmes. The formation of buffer zone has been advantage which has resulted in effective control of the forest fires (KFWD 2012). The present study supports conservation effectiveness in minimizing fire incidents in the core zone. Based on historical analysis, the present study has provided geospatial information on varying frequency of fires which is useful for conservation prioritization of sensitive areas.

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