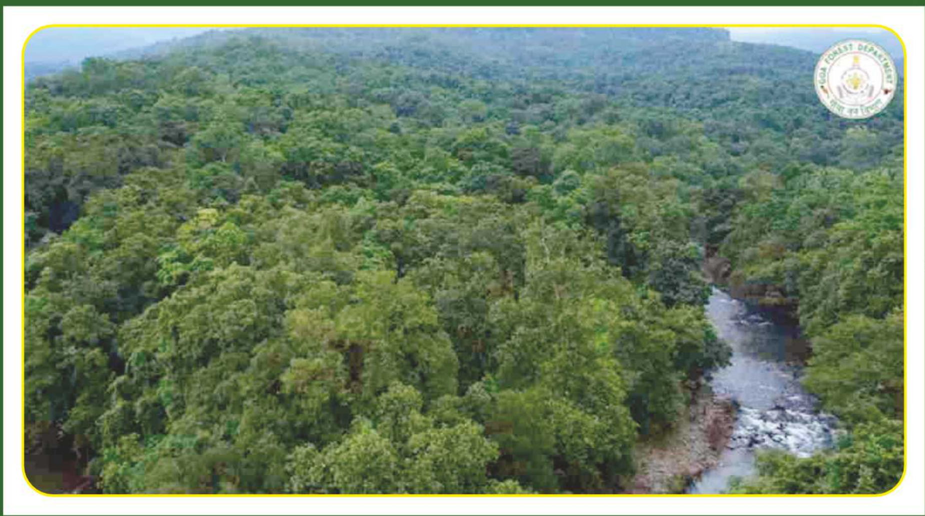
TECHNICAL BULLETIN No. 74

FOREST FIRE PRONE AREAS IN GOA AND THEIR MANAGEMENT



भा.कृ.अनु.प.-केंद्रीय तटीय कृषि अनुसंधान संस्थान

(भारतीय कृषि अनुसंधान परिषद)

ओल्ड गोवा ४०३ ४०२, गोवा, भारत

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(Indian Council of Agricultural Research)

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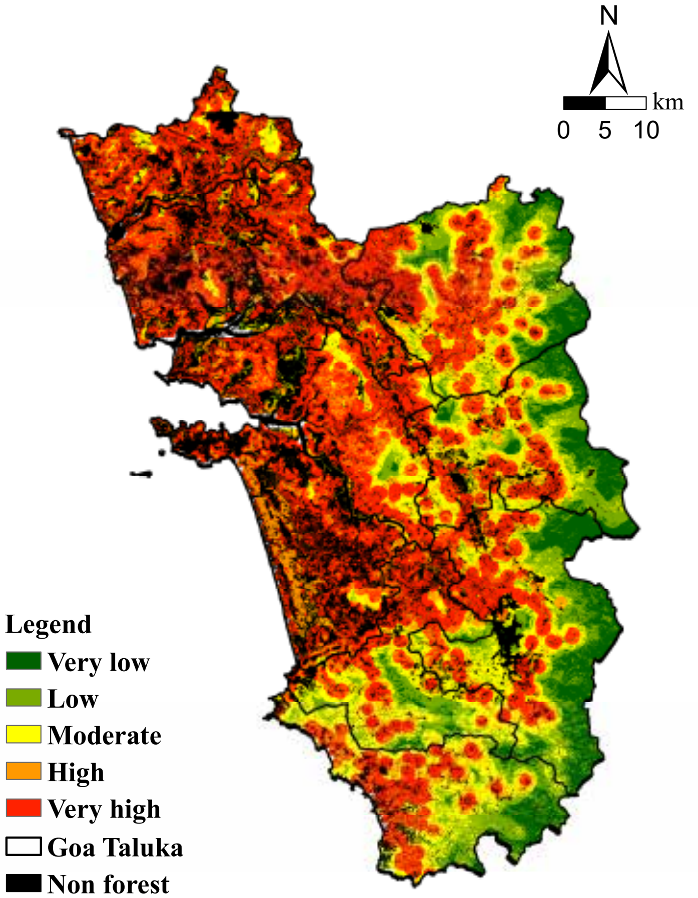

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EXECUTIVE SUMMARY

The forests of Goa have historically not been affected by forest fire due to the high annual rainfall (>3500 mm/yr), influence of the coastal climate and limited biotic disturbances. The forests were also used for cultivation of cashew plantations by the local communities in a mutually symbiotic agreement with the forest department with protection being provided by the cultivators from fire and disturbances.

However, in the last decade anthropogenic disturbances in the form of land use changes due to increasing demand for land, land use conversion, infrastructure development, limited fodder availability, increasing cases of arson by vested interests at the village level and changing climate (increased dry periods, high rainfall in less number of rainy days, high diurnal temperatures) have contributed to an increased frequency of forest fire at various extents.

The ICAR-CCARI, Goa submitted a proposal for undertaking a study on forest fire recurrence in Goa. The proposal was approved by the Research Advisory Committee (RAC) of the State Forest Department with the objectives – (a) to identify different causal factors for forest fires in Goa (b) to map fire prone areas in forest of Goa through remote sensing and GIS (c) to suggest mitigation measures to manage forest fires in Goa.

The analysis carried out after extensive field surveys, reveals that past events of fire incidents in the forests have been due to several reasons which have occurred simultaneously – extended periods of dry hot temperatures, increased availability of fuel (litter & dry grass) on the forest floor, inaccessible areas in many forest areas, accidental or intentional fires which have spread rapidly and lack of adequate measures for fire control. Mapping of forest areas vulnerable to fire has been done using standard techniques in RS & GIS. Nine variables were used and AHP techniques were used to map vulnerable areas in five different classes. Results indicate that a large area (1077.7 sq. km) of forest cover in Goa is now very highly vulnerable to fire followed by highly vulnerable (491.58 sq.km) and 543 sq. km being moderately vulnerable.

A number of mitigation measures covering mechanical, biological, administrative, capacity building and legal strategies have been suggested which upon implementation, will lead to protection of forest areas from fire and also led to improved hydrological functioning and forest recovery in the fire affected areas.

INTRODUCTION

Goa became a Union Territory of India in 1961 and attained statehood in 1987. It is located along the Arabian Sea and has an area of 3,702 sq km which is 0.11% of the geographical area of the country and is bordered by Maharashtra in the North & East and Karnataka in the South. The State lies between14°53'N to 15°40' N latitude and 73°40' E to 74°21' E longitudes. The state has two distinct physiographic regions, namely Western Ghats and coastal plains. Goa has a tropical monsoon climate. The average annual rainfall is 3,800 mm and the average annual temperature ranges between 16°C to 37°C. The State is drained by a number of rivers, the important rivers being Mandovi and Zuari. As per the 2011 census, Goa has a population of 1.46 million accounting to 0.91% of India's population. The urban and rural population is 62.17% and 37.83%, respectively. The Tribal population is 10.23%. The average population density of the State is 394 persons per sq km which is slightly higher than the national average. The 19th Livestock census 2012 has reported a total livestock population of 0.14 million.

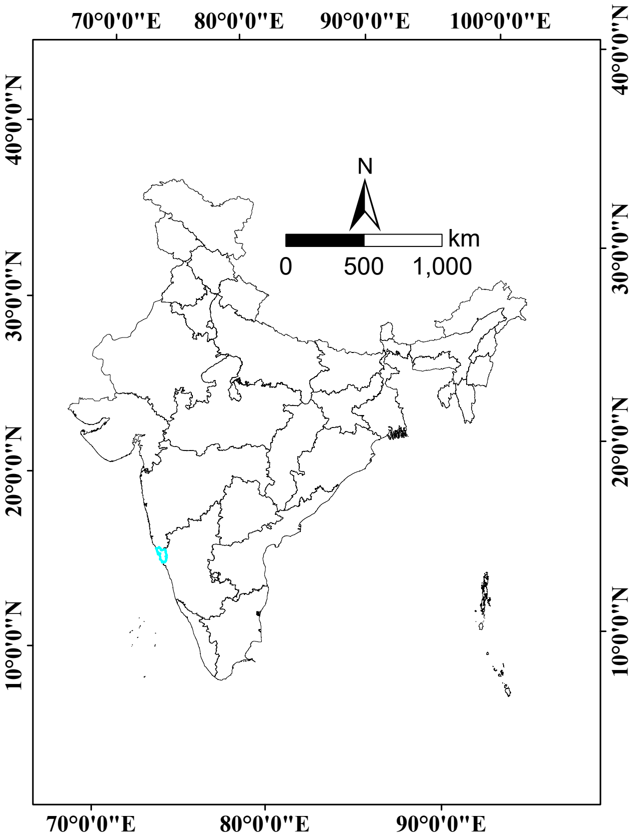
Land use patterns in Goa

Nearly 35% of the geographical area in Goa is under forest cover and another 0.52 % under pastures and miscellaneous tree cover (Table 1) which can be further improved. Out of the 35% under forest cover, a bulk is under deciduous forest cover. Forest cover in Goa and the adjoining states of Karnataka and Maharashtra perform an important role in maintaining the hydrological balance of the Western Ghats which provides precious fresh water to these states by regulating flows in the major rivers like the Zuari, Mandovi, Saleri, Chapora and numerous others tributaries. It is therefore extremely important to maintain these forests at their optimum level in terms of cover and diversity levels.

Table 1: Area under different land uses (in 000' ha)

Sl. No.	Land use type	Area (in 000'ha)	Percentage
1	Geographical area	370	
2	Reporting area	361	100.00
3	Forests	125	34.75
4	Not available for cultivation	37	10.28
5	Permanent pastures and other grazing lands	1	0.36
6	Land under miscellaneous tree crops and groves	1	0.16
7	Culturable wastelands	53	14.55
8	Fallow land other than current fallows	0	0.00
9	Current fallows	15	4.11
10	Net sown area	129	35.79

Source: Land use Statistics, MoA, GoI 2014-15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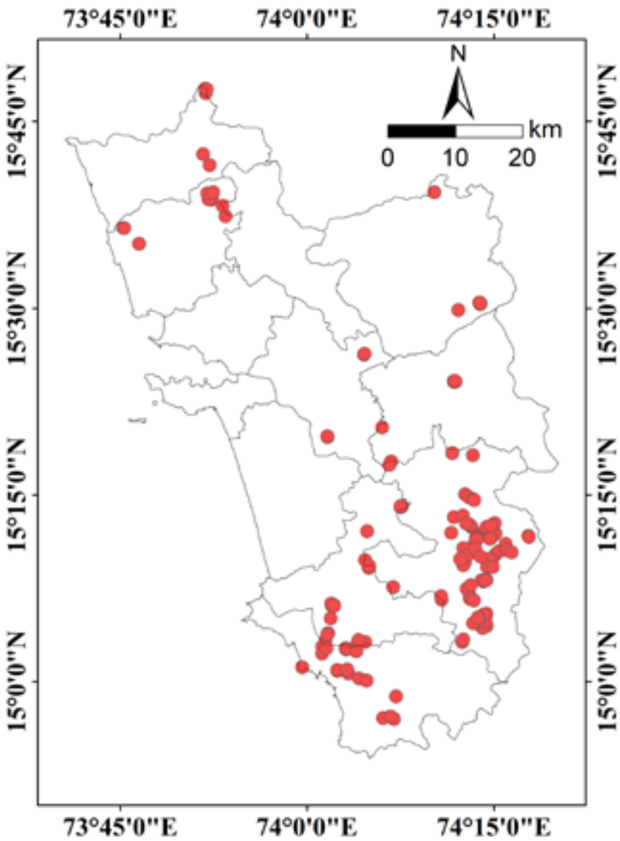
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Study area

Forest types of Goa

The forests of Goa are typical of the Western Ghats (Southern Maharashtra and Karnataka). There is diversity in the forests due to the variation in altitude, aspect, soil characters, slope etc. As per Champion and Seth (1968) Classification of Forest types of India, the forests of Goa fall in the following types:-

(i) Estuarine vegetation consisting of mangrove species along narrow muddy banks of rivers [4 B/TS1 and 4B/TS2]

(ii) Strand vegetation along the coastal belts

(iii) Plateau vegetation confined especially to the low altitude
  a. Open scrub jungle (5.E7)
  b. Moist mixed deciduous forests [3B/C2]
  c. Secondary moist mixed deciduous forests [3B/C2/2SI)
  d. Sub-tropical Hill forests [8A/C2]

(iv) Semi-evergreen and evergreen forest.
  a. Semi-evergreen forests [2A/C2]
  b. Lateritic Semi-evergreen forests [2 E4]
  c. Evergreen forests [1A/C4]

These are briefly described below:

(i) Estuarine vegetation of mangroves along swampy river banks [4 B/TS1 and 4B/TS2]:-

This type occurs in isolated small patches along the banks of Mandovi and Zuari rivers and other salt water streams. Botanically this zone is characterized by peculiar root formations (stilt roots of *Rhizophora*, pneumatophores in *Avicennia*, knee root in *Bruguiera* etc). The mangroves are found in the division mainly at Durbhat, Panaji, Agassaim and Cortalim. The above categories of vegetation occur from sea level to 100m.

(ii) Strand and creek vegetation along the coastal belt: -

Most of the coastal regions of Goa is rocky with projecting ridges. The strand vegetation is limited to a few patches of narrow strip bordering the Arabian Sea. The vegetation along the south bank of the river Mandovi near Panaji belongs to this category. Tree species mainly found are *Pongamia pinnata, Thespesia populinea, Calophyllum inophyllum, Cerbera manghas* and *Pandanus tectorius*. Many herbaceous species such as *Neanotis rheedei, Iphigenia indica, Begonia crenata, Habenaria grandifloriformis, Tricholepis glaberrima, Trichidesma* sp. are found along rocky creeks and projecting ridges facing the coast.

(iii) Plateau vegetation along undulating terrain and hills:

A major portion of the vegetation in Goa belongs to this category, which is further divided into four types viz. (a) Open Scrub jungle, (b) Moist deciduous forests, (c)Secondary moist mixed deciduous forests and (d)Sub-tropical hill forest.

(a) Open scrub jungle (5E7): This type of vegetation occurs from Panaji to Cortalim and from Bicholim to Sanquelim. *Anacardium occidentale* is found on an extensive scale. The vegetation is mainly composed of dry deciduous elements such as *Carissa congesta, Hollarrhena pubescens, Lantana camara, Calycopteris floribunda, Woodfordia fruticosa, Grewia abutilifolia, Vitex negundo* and species of *Calotropis, Ziziphus, Cassia, Ixora, Acacia, Albizia, Terminalia* and *Crotalaria*.

(b) Moist mixed deciduous forests [3B/C2]: This is the main forest type, found in Goa, covering more than half of the forest areas. In North Goa Division, this type occurs around Tudal. Ordofind, Butpal, Molem, Codal, Abiche Gol near Valpoi, and Anmod ghat. Predominant species are *Terminalia crenulata, T. bellirica, T. paniculata, Lagerstroemia parviflora, Adina cordifolia, Albizia lebbeck, A. procera, Mitragyna parvifolia, Holoptelia integrifolia, Trewia nudiflora, Dillenia pentagyna, Semicarpus anacardium, Mallotus philippensis* and *Stereospermum colais*.

(c) Secondary moist mixed deciduous forests [3B/C2/2SI]: Trees found in this type are knotty and of coppice origin. A few trees of primary origin are found scattered. Such type is found mainly in areas of "Kumeri cultivation" and in other areas affected by biotic interferences. The main species found are *Terminalia crenulata, T. chebula, Adina cordifolia, Alstonia scholaris, Lannea coromandelica, Bombax ceiba, Careya arborea* and *Dillenia pentagyna*.

(d) Sub-tropical Hill forests [8A/C2]: These forests have formed due to "Kumeri cultivation" in the past. *Syzygium cuminii* and *Cinnamomum verum* are of common occurrence. *Caryotaurens* is the most common palm in this type of forest. In the second storey, *Strobilanthes callosa, Elaeagnus conferta* and *Capparis* sp. are found.

(iv) Semi-evergreen and Evergreen forests:

(a) Semi-evergreen forests [2A/C2]: This type occurs intermingling between tropical evergreen and moist deciduous forest mostly above 500 m.s.l. and is found at Ambochegol, Molem, Butpal and Nadquem. Species composition is of *Artocarpus hirsutus, A. gomezianus, Calophyllum sp., Sterculia guttata, Kydia calycina, Lagerstroemia microcarpa, Pterospermum diversifolium, Garcinia indica, Diospyros montana* and *Macranga peltata*.

(b) Lateritic Semi-evergreen forests [2 E4]: This type of forests is found on shallow dry lateritic soils. *Xylia xylocarpa* is the prominent tree species with other associates like *Pterocarpus marsupium, Grewia tiliifolia, Terminalia paniculata, Schleichera oleosa, Careya arborea, Bridelia retusa* and *Strychnos nuxvomica*.

(c) Evergreen forests [1A/C4]: This type occurs in deep gorges and depressions and also along the nallahs and streams in the Ponda-Amboli-Rambhat belt. The main species are *Calophyllum calaba, Garcinia gummigutta, Canarium strictum, Lophopetalum wightianum, Myristica sp.,Knema attenuata, Chroisophyllum acuminata, Palaquium ellipticum, Artocarpus gomezians, Diospyrus ebenum, Mangifera indica, Persea macrantha, Mimusops elengi, Hopea ponga, Olea dioica, Hydnocarpus pentendra, Syzygium cumini, Holigarna arnotiana, Litsea coriacea, Mallotus philippensis, Ficus* sp. etc. *Osmunda regilis*, the royal fern, which is rare in the peninsular India, is also found in this type of forest.

Table 2: Distribution of different forest types in Goa

Sl. No.	Forest Type	% of forest cover	Area ('000 ha)
1	West Coast Tropical Evergreen forest	22.40	28
2	West Coast semi-evergreen forest	21.35	26.6
3	Southern moist mixed deciduous forest	42.55	53.18
4	Mangrove forest	1.08	1.35
5	Laterite thorn forest	0.02	0.25
6	Plantation/trees outside forests	12.60	15.75
		100.00	

Source: FSI 2019

Status of forest cover

Based on the interpretation of IRS Resourcesat-2 LISS III satellite data period of Dec 2017, the Forest Cover in the State is 2,237.49 sq km which is 60.44% of the State's geographical area. In terms of forest canopy density classes, the State has 538.00 sq km under Very Dense Forest (VDF), 576.09 sq km under Moderately Dense Forest (MDF) and 1,123.40 sq km under Open Forest (OF) (Table 2 & 3). Forest Cover in the State has increased by 8.49 sq km as compared to the previous assessment reported in ISFR 2017.

However, the area under open forests is higher than that expected given the conducive conditions for forest growth and establishment in the Western Ghats. In view of the significance of dense forest cover in biodiversity conservation in the 'hot spot' and maintenance of hydrological functioning of the entire region, which is a source of major perennial rivers, there is a need to revive the open forest areas by biological means and create conditions for increased tree cover.

Table 3: Status of forest cover in Goa

Sl. No.	Class	Area (in sq.km)	% of geographical area
1	Very dense forest (VDF)	538.00	14.53
2	Moderately dense forest (MDF)	576.09	15.56
3	Open forest (OF)	1123.40	30.35
	Total	2237.49	60.44
	Scrub	0.00	0.00

Distribution of fire prone classes in forests of Goa

The state of Goa has been fortunate, due to natural reasons, that the occurrence of forest fire has been very limited and a very small area is prone to fire, although the intensity of fire has not been reported (Table 4). However, in view of the recent fire incidents caused both due to natural reasons and human factors, there is a need to reclassify the areas prone to fire, after mapping the vulnerable areas.

Table 4: Distribution of forest fire prone classes in Goa

Sl. No.	Forest Fire Prone Classes	Geographical area (in sq. km)	% of total forest cover
1	Extremely fire prone	-	0.00
2	Very highly fire prone	-	0.00
3	Highly fire prone	-	0.00
4	Moderately fire prone	1.10	0.05
5	Less fire prone	3589.82	99.95
		3590.92	100.00

Trends of occurrence of rainfall and high temperature

The role of climate change in increasing the probability of long dry periods after the cessation of the monsoons cannot be denied. The effect of unexpected changes in weather on forest processes are complex and are yet to be completely understood. Increasing air temperatures are expected to change the frequency, severity and extent of wild fires.

The distribution of rainfall in the state over the last two decades is depicted in Fig. 1. The average rainfall has increased at the rate of 8.72 mm/year, but the number of rainy days (>2.5

mm/day) has decreased non-significantly at the rate of -0.06 days/year, indicating that high amount of precipitation is being received in lesser number of days leading to high run off losses, rapid flooding and less infiltration time. This ultimately leads to loss of soil cover, loss of nutrients and build up of soil moisture stress in the post-monsoon period which extends for nearly eight months (October to May).

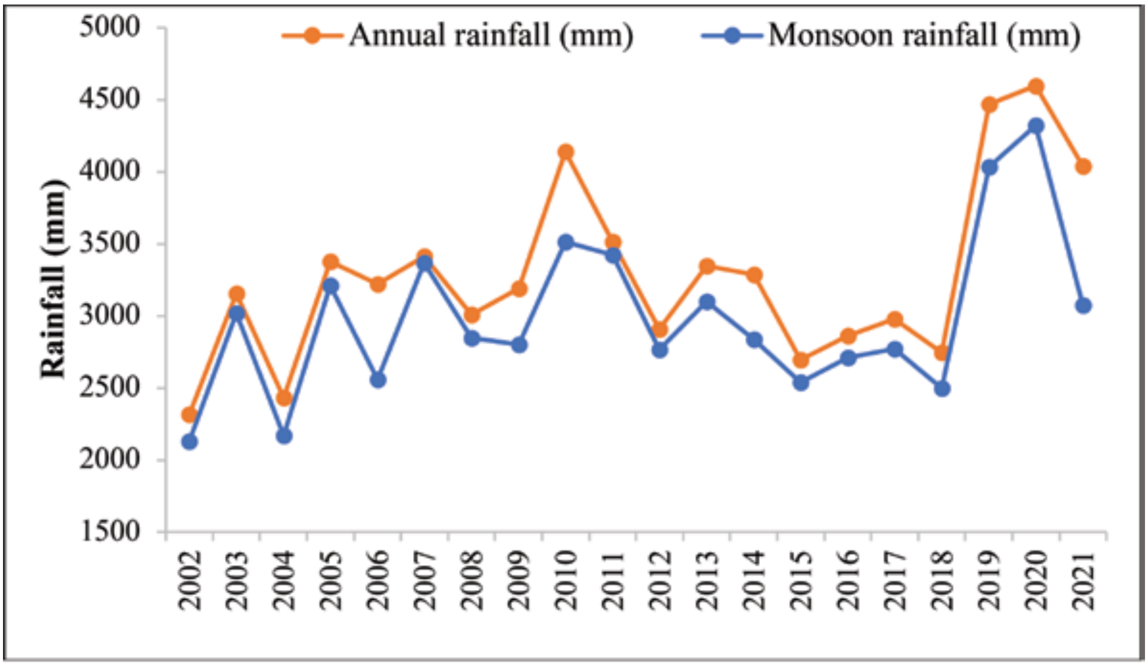


Fig. 1: Distribution of annual and monsoon rainfall in Goa over the last two decades.

Analysis of long term (40 years) data on temperature of Goa has clearly indicated that there is a noticeable change in the daily maximum temperature (T_{max}) which shows an upward trend (Fig. 2) while the minimum temperature (T_{min}) shows a declining trend indicating that diurnal variations in daily temperature will increase in the coming years, leading to more drier conditions all over the state.

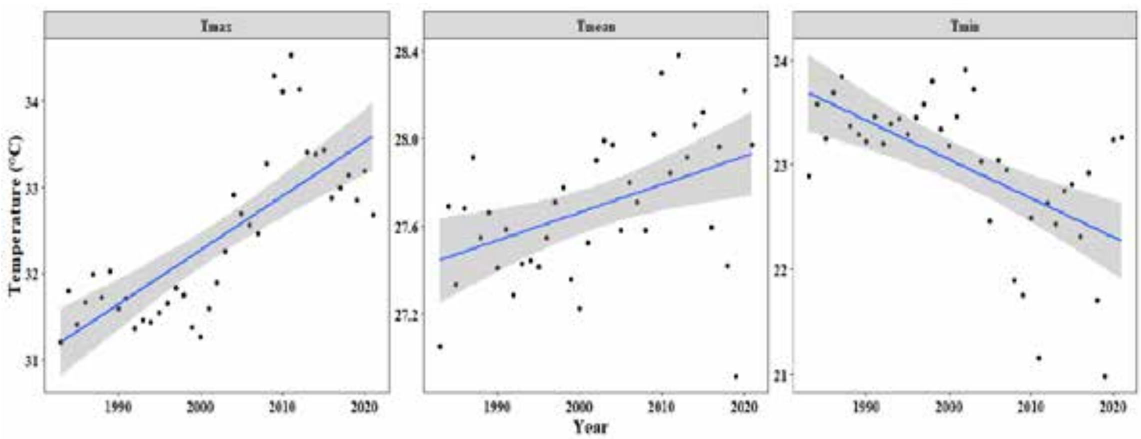


Fig. 2: Long term trends of max. and min temperature in Goa.

Analysis of long term (70 years) trends of rainfall distribution show disturbing trends, with significant increase in total annual rainfall over the years (Fig. 3), that is evident from the annual rainfall being received since 2019, which was nearly 4300 mm in 2019, that increased to 4597 mm in 2020, while the number of rainy days have reduced (Fig. 4).

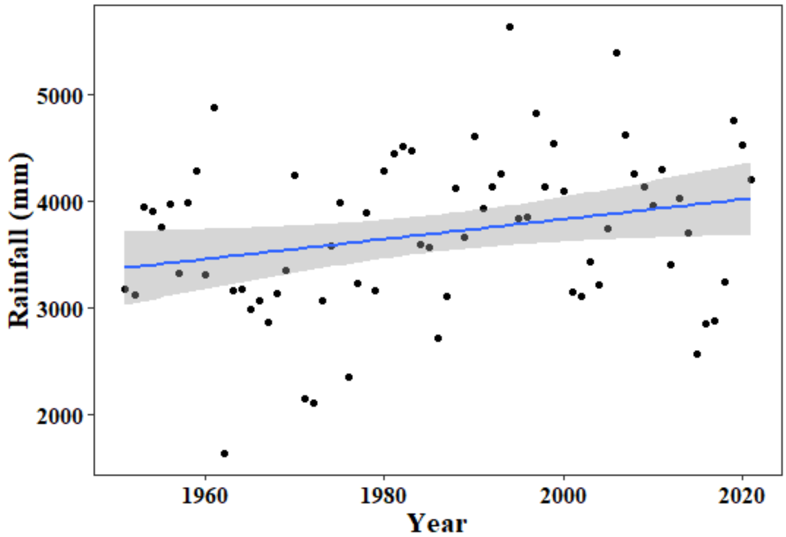


Fig. 3: Long term trends of annual precipitation in Goa.

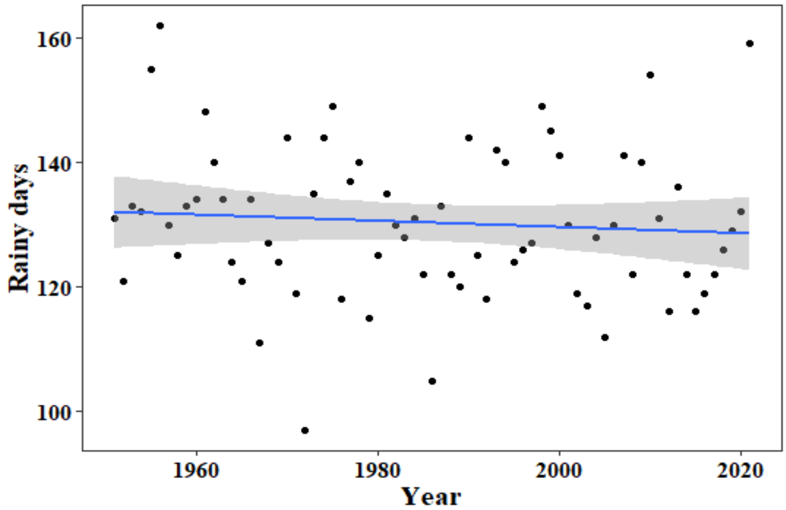


Fig. 4: Long term trends of number of rainy days in Goa.

Methodology followed:

a) Vegetation and soil sampling: Enumeration of vegetation in burnt and unburnt forest and plantation area was carried out during mid –February'23 to the second week of March'22 in 17 locations in both North and South Goa divisions. Quadrats of size 10m x 10m were used which have been reported to be sufficient for analyzing vegetation in similar locations (Raizada & Samra, 2000). All the plant species above 10cm GBH encountered inside the belt transect were considered as trees and girth was measured at breast height (1.37m). For individual trees height was measured from the base of the tree to the tip of the canopy. The tree diversity and biometric data (gbh and height) were recorded. To study the regeneration status 1m x 1m plot was also laid out. In the regeneration plot, all plant species below 10cm GBH were considered as regenerates and enumerated separately.

Diversity indices

Shannon diversity index (H')

Shannon diversity index (Shannon and Wiener, 1949) is a measure of heterogeneity which takes into account the evenness of abundance of species. Shannon index was calculated by using the formula

$$H = \sum_{i=1}^{n} P_i \ln P_i$$

Where 'Pi' is the proportion of individuals of i^{th} species relative to the total number of species; 'n' is the total number of species.

Quotient of similarity (Qs)

On the basis of the number of species under each community was measured (Sorenson 1941) as:

$$Qs = \frac{2c}{a+b} x100$$

Where a and b are the number of species in A and B communities and c is the number of species common in both the communities.

Importance Value index(IVI)

IVI was calculated to determine the dominant species in a community (Curtis and McIntosh, 1951). This index is also a good indicator of potential vegetation composition in the area. The maximum value of IVI can take is 300, since three different percentages are added and each can attain a maximum value of 100. IVI was computed by using the formulae as mentioned below:

IVI = Relative frequency + Relative density + Relative dominance

Where,

Relative frequency = (Number of plots containing a species X 100)/sum of frequencies of all the species.

Relative density = (Number of individuals of a species X 100)/ total number of all individuals.

Relative dominance = (Basal area of a species X 100)/total basal area of all species.

Soil samples were collected from depths of 0-30 cm at each vegetation sampling point and analyzed for organic carbon using the modified Walkley and Black wet oxidation method (Jackson,1967)

b) Forest fire conditioning factors

Various factors affecting forest fire occurrence were collected from different sources. In the current assessment, nine factors responsible for forest fire were considered, namely - elevation (m), slope (%), aspect, topographic wetness index (TWI), forest cover types, average normalized difference vegetation index (NDVI), distance to road, distance to settlement, and land surface temperature (LST, °C). The details of the dataset used for forest fire vulnerability mapping is provided in Table 5.

Table 5: Details of datasets, source and spatial resolution of forest conditioning factors

Dataset	Variables	Source	Spatial Resolution
SRTM DEM	Elevation, slope, aspect, TWI	https://earthexplorer.usgs.gov/	30 m
Forest cover map	Forest type	https://fsi.nic.in/introduction	1:50,000
ESA 2021 Land Cover	Distance to settlement	https://esa-worldcover.org/en/data-access	10 m
MODIS	NDVI	https://earthexplorer.usgs.gov/	250 m
MODIS	LST	https://earthexplorer.usgs.gov/	1 km
Road network	Distance to road	https://www.openstreetmap.org/	

Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) was downloaded from Earth Explorer. The DEM was filled using the fill tool available in ArcGIS. The filled DEM was used to generate slope, aspect, TWI. Time series MODIS 8-day composite daytime LST data at 1 km resolution (MOD11A2) for 2001-2022 was downloaded using Google Earth Engine. The LST in degree Celsius (°C) was calculated by multiplying the digital numbers with 0.02 and subtracting 273.15. Similarly, for NDVI, time series MODIS 16-day composite at 250 m resolution (MOD13Q1) for the same period was downloaded from Google Earth Engine.

The World Cover land use/land cover (LULC) prepared by European Space Agency (ESA) for the 2021 was used for computation of distance to settlement, using Euclidian distance tool in ArcGIS. Similarly, the road network downloaded from Open Street Map (OSM) was used to calculate distance to road. All the forest fire conditioning factors were projected in Universal Transverse Mercator (UTM) coordinate system, zone 43^0 N and WGS 1984 datum at 30 m spatial resolution.

Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was used to compute the weights for forest fire conditioning factors and sub-classes of each factor. The weights were assigned in such a way that a factor with higher weight had a greater influence on forest fire risk. Experts opinions based on 1-9 scale (Table 6) were used to generate pairwise comparisons matrices for conditioning factors and subclasses(Saaty 2008).

Table 6: Scale of comparison pair for AHP (Saaty, 1996)

Description	Numeric Rating	Reciprocal
Extremely importance	9	1/9
Very strong to extremely	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong importance	5	1/5
Moderately to strong	4	1/4
Moderate importance	3	1/3
Equally to moderately	2	1/2
Equal importance	1	1

Reliability of pairwise comparisons matrices generated based on expert opinion were evaluated using consistency ratio (CR). CR can be calculated using the following equation

$$CR = \frac{CI}{RI}$$

where RI is random index indicating the consistency index of randomly generated pairwise matrix shown in Table 7 and CI is the consistency index which was computed using following formula

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Where λ_{max} is the largest matrix eigenvalue, n is the number of thematic layers.

CR less than 0.10 indicates acceptable consistency of pair-wise comparison and weight calculation. If the CR is more than 0.10, the pair-wise comparison has to be modified until it is reduced below 0.10.

Table 7: Random Consistency Index up to 15 layers (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

Validation

In this study, a forest fire inventory containing 147 locations was collected from Department of Forest, Government of Goa and filed surveys. In addition to this, 95 locations with no record of forest fire were also collected. The forest fire inventory was also used to generate the receiver operating characteristic (ROC) curve. Further, the area under the ROC curve (AUC) was computed which varies between 0 and 1. AUC values near 1 indicate excellent model performance, while values near 0.5 indicate poor model performance. The flowchart used for the current study is depicted in Fig. 5.

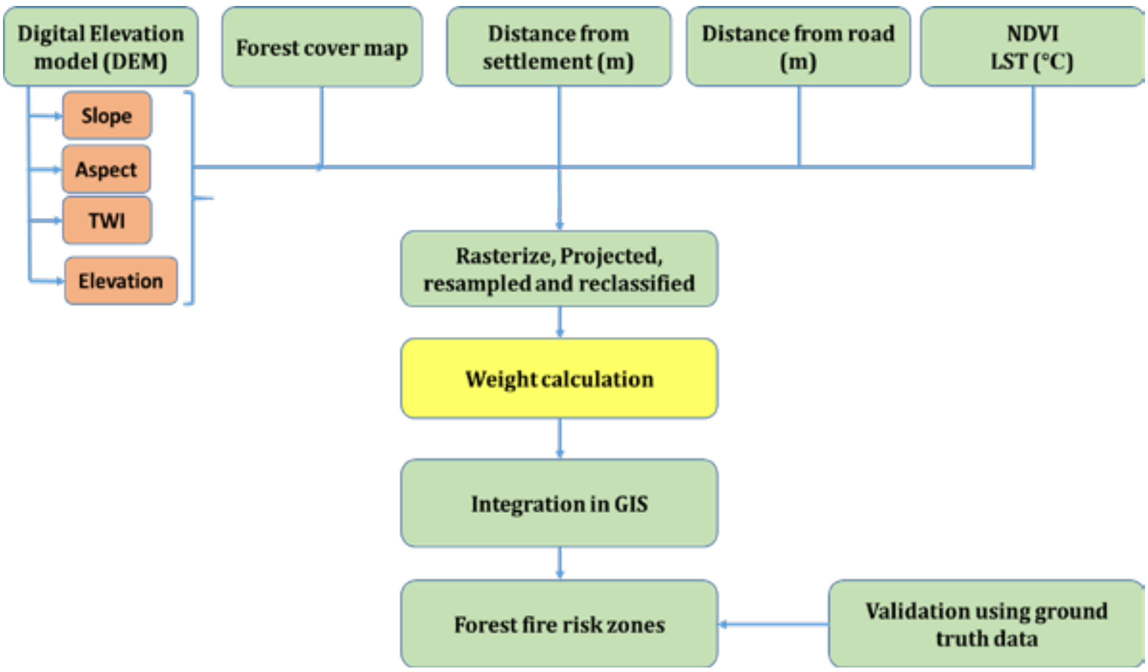


Fig. 5: Flow chart indicating procedure followed to prepare vulnerability maps.

Environmental and economic loss caused by forest fires in India

Forest fires also called as bushfire (in the savannahs) or vegetation fire are caused by natural or man-made reasons in tropical, temperate and boreal forests. A fire must have three conditions to burn – fuel (trees, grasses, forest litter), oxygen and a heat source. The intensity of a fire is proportional to the amount of fuel present in a region or area. Lightning, smoldering campfires, cigarettes, petrol, kerosene, diesel can all ignite fires which gets further aggravated by breeze or wind blowing in the area.

Man-made reasons like throwing a burning cigarette butt, sparks from exhaust pipes of moving vehicles along roads, forest clearing under slash & burn cultivation have historically caused extensive damage to forest area all over the world. In some countries, poor management (absence of controlled burning, absence of fire lines, thick accumulation of forest debris) of forests have also led to extensive fires which have burned huge areas of forests over several weeks, causing loss of billions of rupees, loss of human life and wildlife and even in some cases led to the migration of birds and wildlife. Under very dry conditions, wild fires can also occur due to spontaneous combustion of dried vegetation.

Forest fires cause significant environmental damage, which can take decades to recover. Wildlife, plants (trees, grasses, regrowth, herbs and shrubs), micro-organisms, insects, homes and hutments, animal shelters are all destroyed. Along with this, hundreds of nests with eggs or chicks are also burnt, forcing many avian species to compete disappear from the forests for many more years, leading to absence of pollinating agents and a consequent poor fruit setting in the surviving trees.

Surface fires destroy all organic matter, which is turned into ash and is washed away during the rainy season, along with the death of hundreds of soil borne insects etc. Smoke from burning forests leads to wide spread air pollution, haziness in the sky and allergic reactions to children and patients who suffer from breathing issues. Economically also, the losses are enormous and it has been estimated that the annual losses from forest fires in India for the entire country is Rs 440 crores (US$ 107 million). This estimate does not include the loss suffered in the form of biodiversity, nutrient and soil moisture and other intangible benefits. India witnessed the most severe forest fires during the summer of 1995 in the hills of Uttaranchal and Himachal Pradesh in north west Himalaya. An area of 677,700 ha was affected by fires. The quantifiable timber loss was around Rs. 17.50 crores (US$ 43 million).

Based on the forest inventory records, 54.40% of forests in India are exposed to occasional fires, 7.5% to moderately frequent fires and 2.40% to high incidence levels while 35.71% of India's forests have not yet been exposed to fires of any real significance. Nearly 10.66% area of Forest Cover in India is under extremely to very highly fire prone zone, as per the long-term trend analysis performed by the FSI. States in the North-Eastern region, show the highest tendency of forest fire, since these states fall under extremely to very highly forest fire zones. States like Mizoram, Tripura, Meghalaya, and Manipur in North-Eastern Part of India exhibit the highest forest fire probability in term of its frequency of event occurrence, which is mostly caused by *jhum* cultivation. Parts of western Maharashtra, southern part of Chhattisgarh, central part of Odisha and few parts of Andhra Pradesh, Telangana and Karnataka also show patches of extremely and very highly fire prone zones.

Fire regime characteristics (area, frequency & severity) are the product of many individual fires, so both weather and climate including short and long term 'dry spells' are important. Depletion of soil and atmospheric moisture also leads to low moisture in foliage and surface combustible material (litter & forest debris) which are the potential starting points of wild fire. Under continued dry spells, both living and dead fuel material can dry out and become flammable and probability of ignition increases along with the rate of fire spread.

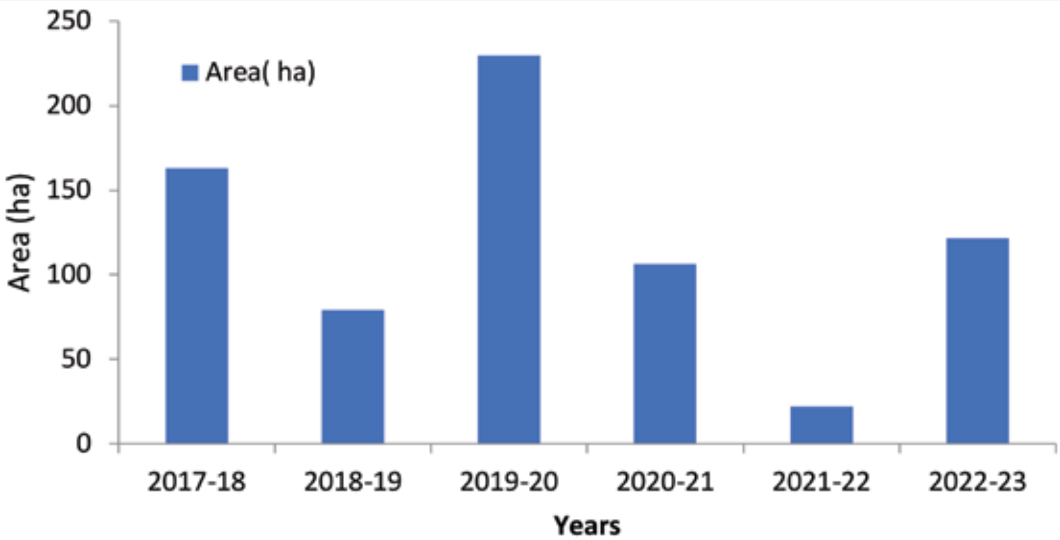
Results

Occurrence of fire in forests of Goa

Nature has been generous enough to have provided the state with bountiful rainfall extending for nearly four months along with a humid weather due to the proximity of the sea. As a consequence, the forest composition and bio-physical factors have been conducive for forest growth and establishment. Historically, incidents of fire have been very few in Goa mostly caused either due to accidental events near human settlements or due to natural causes.

Assessment of forest fire occurrence in Goa (North & South districts) reveal that over the five-year period from 2017 till January 2023 an area of 521.29 ha was affected by fire, most of which was surface fire, with the largest area affected during 2019-20 (Fig. 6). Keeping in mind that these years have received sufficient amount of precipitation, it is expected that the growth of understorey vegetation – grasses and annual vegetation, would have occurred in significant amounts. However, while it is not easy to accurately pinpoint the actual reasons for the sudden surge in fire incidents, it is likely that these events have been caused by several activities that may have taken place in the fire affected areas – (a) access of rural population to forest areas for harvesting of grasses soon after the rainy season for their livestock, (b) setting up of surface fire during the dry periods to induce vegetative growth in grasses, (c) high levels of forest detritus which has become very dry in the absence of *in-situ* soil-water conservation practices in the forested areas and (d) unauthorized forest clearing for the establishment of cashew plantations.

During the recent field assessment carried out at different sites, it was noticed that litter quantities were in the range of 1.2 to 10.2 tons/ha in unburnt areas and 1.6 to 5.1 ton/ha in burnt areas, which was very dry and undecomposed due to the complete absence of moisture. It is these large quantities of forest debris which acts as fuel even for a small fire to spread rapidly. Excavation of staggered contour trenches of a suitable size will lead to moisture and soil retention in the forest areas, encourage litter decomposition and humus build up.



Total area (ha) affected by all types of fire incidence during different years in Goa (period of 2023 reported is only upto Jan.'23)

Fig. 6: Total area (ha) affected by forest fire in different years in Goa.

Damage caused by fire

Visuals of different types of forests and plantations damaged by fire during the last years and during the summers of May 2022 are presented in the following plates (Plates 1-20). Perusal of these photographs indicate that while fires have been frequent, they have not caused significant damage to the canopy but have destroyed all understorey vegetation which also includes grasses and natural regeneration. Conducive precipitation and limited protection in some areas have also led to regeneration of desired species in some forest areas.

Plate 1: *Acacia auriculiformis* tree burnt due to forest fire in the Usgao range, Social Forest Division

Plate 2: Ground fire in *Acacia auriculiformis* plantation in the Usgao range, Social Forest Division

Plate 3: Mortality of soil fauna (millepedes – primary decomposers) due to forest fire.

Plate 4: Ground fire in *Acacia auriculiformis* plantation in the Tivim range, Social Forest Division

Plate 5: Laying out of sample plots, measuring of tree girth and collection of litter and soil sample in fire affected area in Satpal range, Research and Utilization division Margao

Plate 6: Forest area not affected by fire in Satpal range, Research and utilization division Margao

Plate 7: Well-maintained fire line along a forest road in Padi (Pissornem) range, South Goa Forest Division

Plate 8: Fire affected area in Padi range, South Goa forest division Margao

Plate 9: Forest area not affected by fire in Padi range, South Goa forest division Margao

Plate 10 : Accumulation of litter and absence of fire line along the roads

Plate 11: Collection of litter in the fire affected plot, Nunem, Netravali Wildlife Sanctuary

Plate 12: Measuring biometric data in fire affected area in Nunem, Netravali Wildlife Sanctuary

Plate 13: Two views of unburnt area in Nunem, Netravali Wildlife Sanctuary

Plate 14: Grasslands which was affected by fire in the Netravali Wildlife range
(Note the complete absence of grass cover)

Plate 15: Fire affected area near Mainapi Waterfall, Netravali Wildlife Range.
(Note the leafless trees and dried leaves on the surface which is a potential fire hazard)

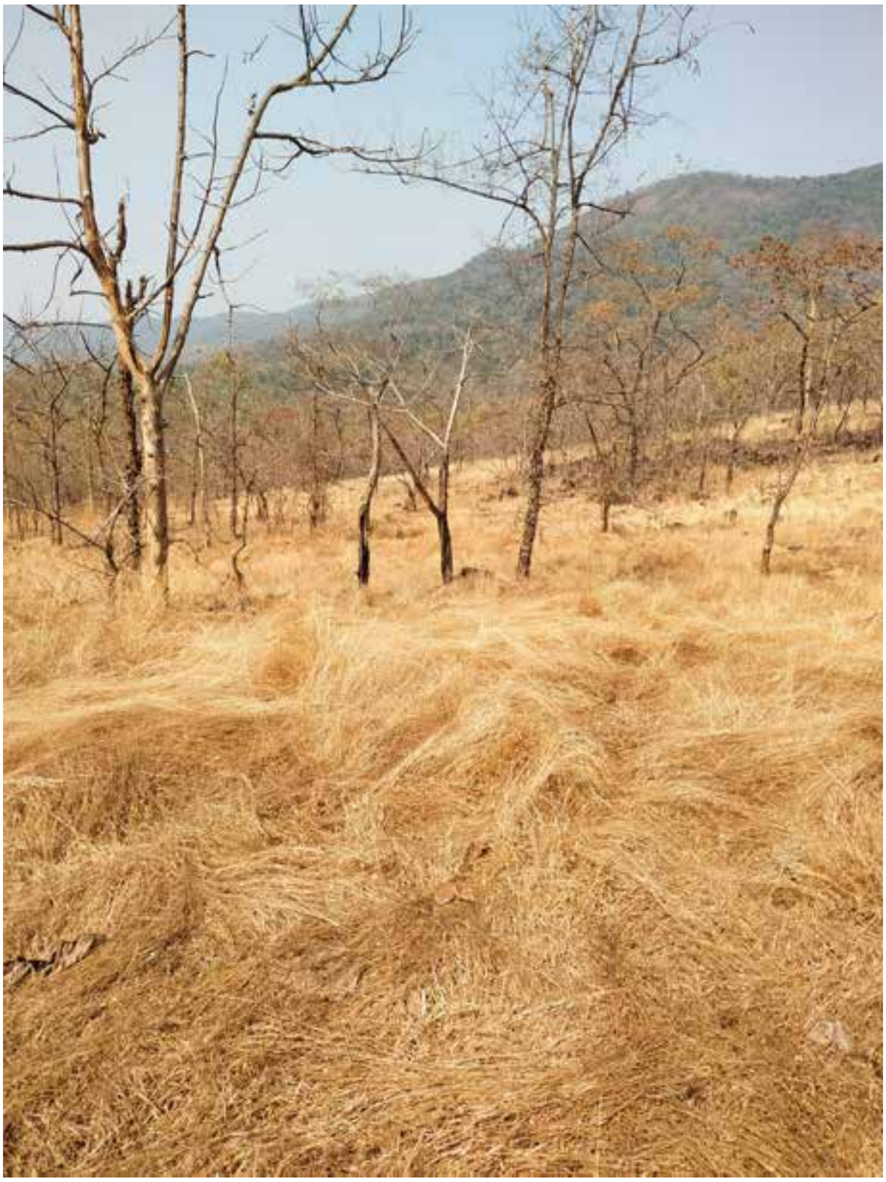


Plate 16: Dry grass in natural forest in Netravali Wildlife Range
(Note the large amount of dry biomass present as combustible material)

Plate 17: Fire lines covered with litter indicating the need of their regular maintenance

Plate 18: Forest fire affected area in Colomba beat, South Goa Forest Division

Plate 19: Fire affected area in Pirla beat, Quepem range, South Goa forest Division

Plate 20: Fire unaffected area in Pirla beat, Quepem range, South Goa forest Division

Status of forest diversity in burnt and unburnt areas

Species richness and diversity

The values of species richness and Shannon's diversity index for tree and regeneration of burnt and unburnt in different forest areas of Goa are presented in Table 8 and 9. Species richness of trees in burnt and unburnt areas were 10 and 15, respectively. The Shannon's diversity index for trees was higher in unburnt (2.27) compared to fire affected (1.70). Both diversity and species richness was higher in unburnt areas. Species richness of regeneration in fire affected and unaffected areas were 18 and 21, respectively. The Shannon's diversity index for regeneration was similar in fire unaffected (2.56) and fire affected (2.55) areas. These trends indicate that surface fires of moderate intensity have not seriously impacted the regeneration of existing species, but, given the change in rainfall pattern and absence of moisture conservation practices, regenerating species will face moisture stress until the arrival of the monsoons.

Table 8: Species richness and diversity of trees in fire affected and unaffected areas in different forest areas of Goa

	Burnt	Unburnt
Species richness	10	15
Shannon's diversity	1.70	2.27

Table 9: Species richness and diversity of regeneration in fire affected and unaffected areas in different forest areas of Goa

	Burnt	Unburnt
Species richness	18	21
Shannon's diversity	2.55	2.56

Coefficient of similarity

The Sorensen similarity (overlap) index measures the overlap between two populations by taking the ratio of the number of species shared between the two populations, relative to the number of species in both populations. The Sorenson's index revealed that, the similarity between trees in burnt and unburnt area was 56, while in regeneration the similarity was 67 (Fig. 7).

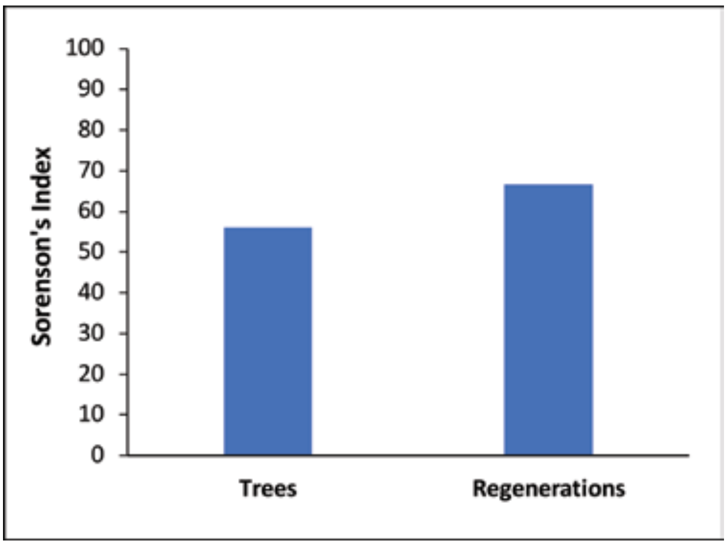


Fig. 7: Quotient of similarity of trees and regenerations in burnt and unburnt areas indifferent forest divisions of Goa

Importance Value Index (IVI) of trees in forest area

IVI gives the importance of species in the community, by assigning rank to individual species based on the pooled data of relative density, relative dominance and relative frequency. In the burnt area, *Terminalia tomentosa* (95.70) tops the list followed by *Tectona grandis* (74.36) and *Terminalia paniculata* (57.83) (Fig. 8). In the unburnt area, *Terminalia paniculata* (59.15) tops the list followed by *Terminalia tomentosa* (53.16) and *Tectona grandis* (34.40) (Fig. 8). Resource sharing and niche space occupation are frequently shown by dominance diversity curves. Wide curves signify stability of the community as seen in unburnt areas.

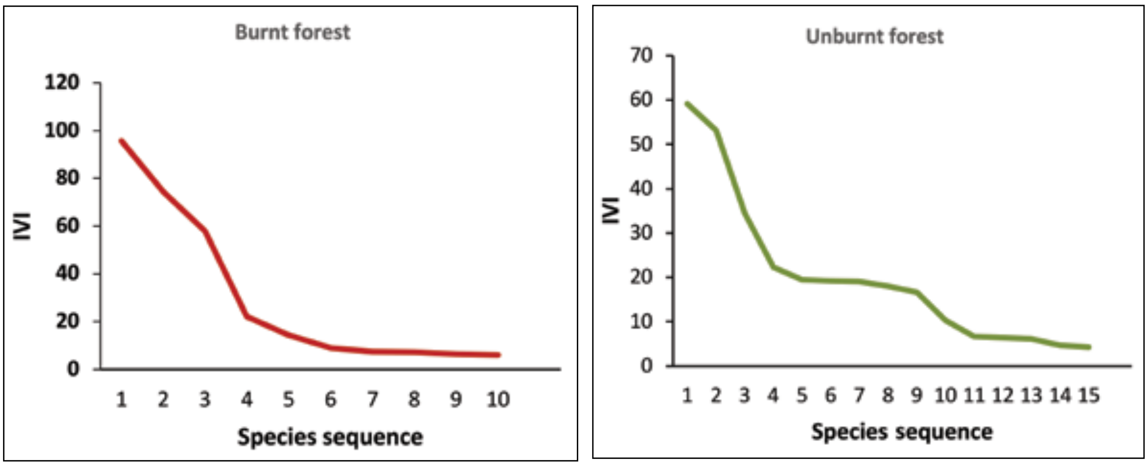


Fig. 8. Dominance diversity curve of tree species in burnt and unburnt areas in different forest divisions of Goa

IVI of regeneration in forest areas

In the burnt area, IVI of tree seedlings, *Terminalia paniculata* (56.48) tops the list followed by *Xylia xylocarpa* (35.33) and *Holarrhena antidysenterica* (28.13) (Fig. 9), while in the unburnt area, *Xylia xylocarpa* (61.11) tops the list followed by *T. paniculata* (44.44) (Fig. 9). The regeneration of existing species in the burnt and unburnt areas indicate that propagules and seedlings have not been significantly affected by the low intensity surface fire, but, recurring fires on an annual basis may create difficulties in the survival and regeneration of the native species.

In the burnt area, IVI of herbs and shrubs *Naregamia alata* (50.21) tops the list followed by *Randia dumetorum* (44.67) and *Ixora coccinea* (27.25) (Fig. 10). In the unburnt area, *Eupatorium odoratum* (47.75) tops the list followed by *Ixora coccinea* (40.07) and *Naregamia alata* (22.84) (Fig. 10). In regeneration also we can observe comparatively wider curve in unburnt area compared to burnt area indicating stability of the community. The occurrence of invasive exotic weed like *Eupatorium odoratum* in unburnt areas is an issue of concern. It appears that the overhead canopy is not dense enough and allows pioneer weed species to invade the area. It is suggested that gap filling with the same climax species be taken up, so that ecosystem stability is improved and open canopy patches are closed at the earliest.

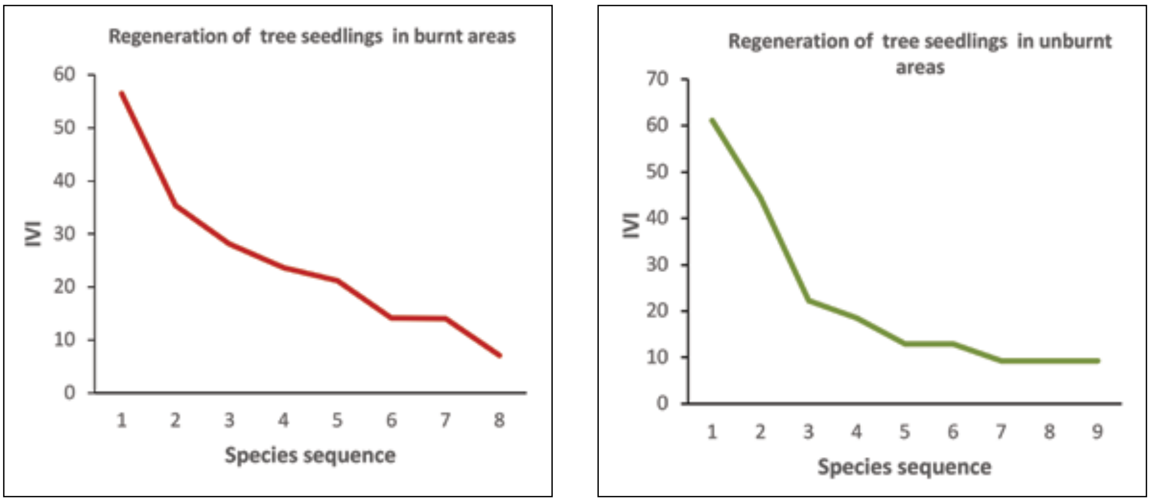


Fig. 9: Dominance diversity curve of regeneration of tree seedlings in burnt and unburnt areas in different forest divisions of Goa

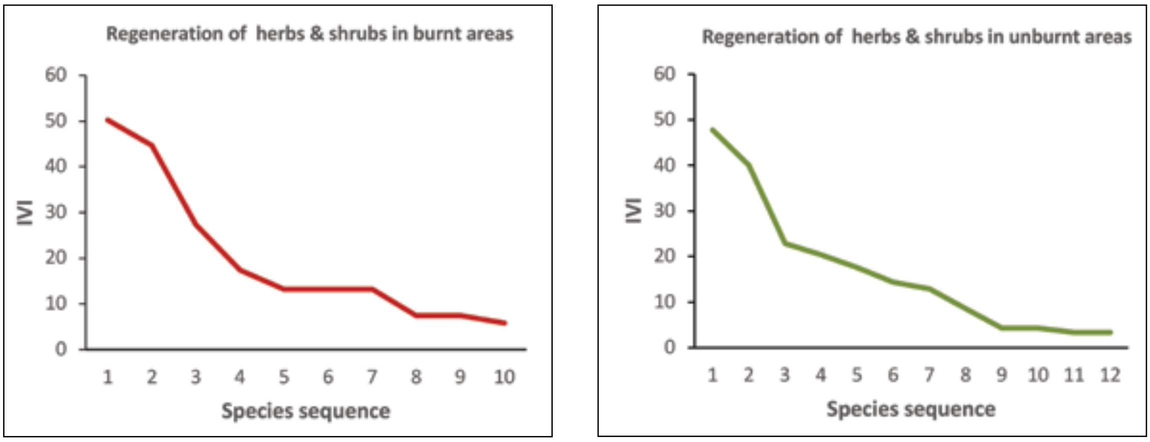


Fig. 10: Dominance diversity curve of regeneration of herbs and shrubs in burnt and unburnt areas in different forest divisions of Goa

Occurrence of combustible surface fuel in different locations

Leaf litter was measured in 1m x1m quadrats laid out randomly in the selected areas, and weight was recorded. Tree litter quantities were significantly high in all areas although no trend was noticed (Table 10). Litter was absolutely dry due to the lack of moisture and higher than normal temperatures and is a readily combustible material in all forest types.

Soil organic carbon

Carbon storage is regarded as a standard metric to assess the ecosystem services and is an indicator of an ecosystem's resilience to climate change. Carbon sequestration is a process in which plants absorb atmospheric CO_2 which is converted into carbohydrates through photosynthesis and stored as plant biomass. Plants are known to absorb 3.67 units of CO_2 to form one unit of carbon stored in plant tissues for every 2.2 tonnes of wood produced, one tonne of carbon is sequestered. When a plant dies, the live biomass gets converted into detritus, and a fraction of the carbon enters the soil after decomposition. Plantations are therefore viewed as the quickest and cost-effective mechanism to absorb atmospheric CO_2 and store in its varied pools such as aboveground biomass, belowground biomass, and detritus comprising of deadwood and forest floor litter, soil, and wood. However, the carbon storage of any plantation depends on many factors such as the species planted, its sequestration potential, age, structure, management, site history, and local climate.

Soil organic carbon (SOC) is a measureable component of soil organic matter. Organic matter makes up just 2–10% of most soil's mass and has an important role in the physical, chemical and biological function of agricultural soils. SOC refers only to the carbon component of organic compounds. Sequestering carbon in SOC has been suggested as one way to mitigate climate change by reducing atmospheric carbon dioxide. The argument is that small increases of SOC over very large areas in agricultural and pastoral lands will significantly reduce atmospheric carbon dioxide.

Results of the analysis (Table 11) revealed lesser organic carbon and soil organic matter in the burnt areas in comparison to the unburnt areas. However, these differences are not significant, given the fact that plantations have been raised in hitherto natural deciduous forests where organic carbon levels must have been high and over several years due to erosion this valuable resource has been washed away.

Table 10: Tree density (no.'s/ha) and litter quantities (kg/ha)* available in different locations under two burn scenarios.

Site no.	Burnt areas		Unburnt areas		Remarks
	No. of trees/ha	Litter (kg/ha)	No. of trees/ha	Litter (kg/ha)	
1	700	4121	700	2518	Natural forest with dominance of teak in the Netravali wildlife sanctuary
2	1200	3646	600	5268	Moist deciduous forests with teak, *T. tomentosa*, *T. paniculata*
3	-	-	-	-	Grassland with scattered trees of *T. tomentosa*, *T. paniculata* & *C.arborea* trees
4	900	4138	400	10222	Teak plantation in deciduous forest area
5	400	3491	1000	2837	Deciduous forests
6	1100	2202	1000	2811	Deciduous forests
7		2487.5	-	1336	Barren land with fresh planting done in 2020-21
8	800	1890	800	5260	*A. auriculiformis* plantation
9	800	1790	1100	6510	*A. auriculiformis* plantation
10	c	960	1100	1920	*A. auriculiformis* plantation
11	1000	1874.5	900	1200	Deciduous forests
12	200	5092	600	-	Deciduous forests
13	800	3760	1600	5492	Deciduous forests
14	700	2018	700	3444	Deciduous forests
15	-	-	-	-	Grassland with stunted trees
16	600	4328	800	7570	*A. auriculiformis* plantation with gap filling of new seedlings

weight reported is dry weight; c – currently existing only as a grassland; * also includes woody debris

Table 11: Soil organic carbon (SOC) and soil organic matter (SOM) at various locations.

Site no.	SOC %		SOM%		
	Burnt	unburnt	Burnt	unburnt	Remarks
1	5.28	7.39	9.11	12.75	*A. auriculiformis* plantation
2	5.85	5.49	10.08	9.47	*A. auriculiformis* plantation
3	3.24	5.77	5.58	9.96	Deciduous forest
4	4.23	5.49	7.28	9.47	Deciduous forest
5	4.23	5.49	7.28	9.47	Deciduous forest
6	3.24	4.08	5.58	7.04	Deciduous forest
7	4.37	4.93	7.53	8.50	Deciduous forest
8	4.08	3.24	7.04	5.58	Deciduous forest
9	2.54	3.24	4.37	5.58	Deciduous forest
10	6.90	6.62	11.90	11.41	Deciduous forest
11	1.13	5.77	1.94	9.96	*A. auriculiformis* plantation

Forest Fire during March- April, 2023

Status of forest diversity in burnt and unburnt areas

Species richness and diversity

The values of species richness and Shannon's diversity index for tree and regeneration of burnt and unburnt in different forest areas of Goa are presented in Table 12 and 13. Species richness of trees in burnt and unburnt areas were 21 and 23, respectively. The shannon's diversity index for trees was higher in unburnt (2.50) compared to fire affected area (2.43) though not significant. This indicates that the ground/ surface fires have not affected the trees.

Species richness of regeneration in fire affected and unaffected areas were 16 and 23, respectively. The Shannon's diversity index was higher in unburnt area (2.34) than the fire affected (2.01). This reveals that fire has impacted the regeneration and undergrowth. During our field survey we could notice that, most of the regeneration and undergrowth was completely burnt (Plate 21-23).

Table 12: Species richness and diversity of trees in fire affected and unaffected areas in different forest areas of Goa after the forest fire incidence of March-April, 2023

	Burnt	Unburnt
Species richness	21	23
Shannon's diversity	2.43	2.50

Table 13: Species richness and diversity of regeneration in fire affected and unaffected areas in different forest areas of Goa after the forest fire incidence of March-April, 2023

	Burnt	Unburnt
Species richness	16	23
Shannon's diversity	2.01	2.34

Importance Value Index (IVI) of trees in forest area

In the burnt area, *Xylia xylocarpa (52.77) and Terminalia paniculata* (52.62) tops the list followed by *Terminalia tomentosa* (40.96) (Fig. 11). In the unburnt area, *Terminalia paniculata* (78.53) tops the list followed by *Xylia xylocarpa* (60.83) and *Terminalia tomentosa* (40.51) (Fig. 11). By ranking each species based on the combined statistics of relative density, relative dominance, and relative frequency, IVI determines the significance of each species in the community. Dominance diversity curves usually demonstrate resource sharing and occupants of specialized spaces. Unburned areas have wider curves, which represent the stable community.

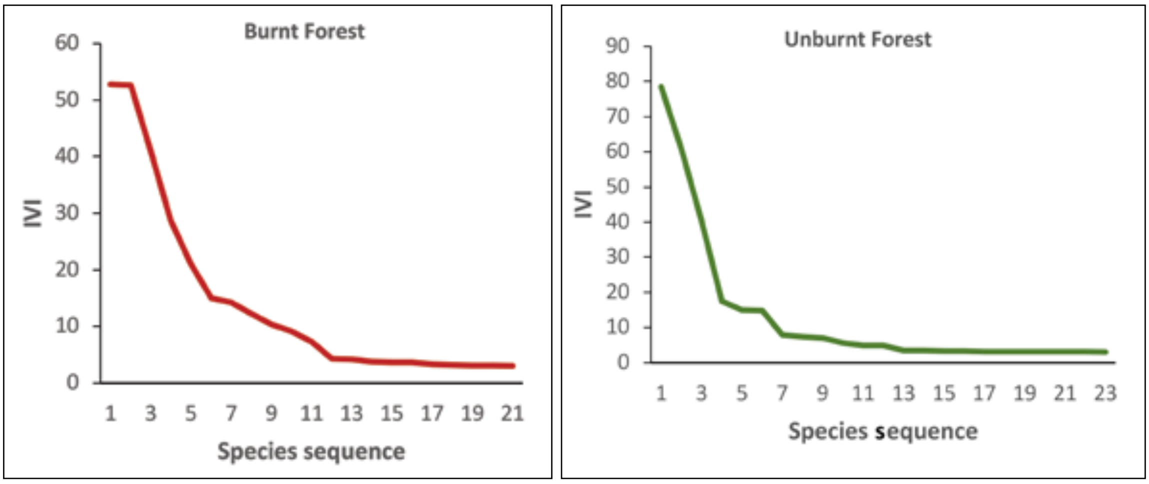


Fig. 11. Dominance diversity curve of tree species in burnt and unburnt areas in different forest divisions of Goa after the forest fire incidence of March-April, 2023

Plate 21: Fire affected area in Pilliem, Ponda Range, North Goa territorial division

Plate 22: Fire affected area in Sulcorna beat, Quepem range, South Goa territorial forest division

Plate 23: Fire affected area in Cumari beat, Netravali Wildlife Sanctuary, South Goa wildlife forest division

Plate 24: Fire affected area in Gurkhem beat, Collem range, North Goa territorial forest division

Plate 25: Fire unaffected area in Gurkhem beat, Collem range, North Goa territorial forest division

Plate 26: New regeneration after the incidence of forest fire in different forest divisions of Goa

IVI of regeneration in forest areas

In the unburnt area IVI of tree seedlings, *Xylia xylocarpa* (61.17) tops the list followed by *Terminalia paniculata* (56.09) and *Tabernaemontana heyneana* (31.16) (Fig. 12). In the burnt area, *Xylia xylocarpa* (109.38) tops the list followed by *Tabernaemontana heyneana* (43.75) and *Terminalia tomentosa* (22.50). The number of new recruit species were higher in unburnt area (10 species) (Plate 25) compared to burnt area (5 species) indicating that regeneration of tree seedlings are adversely affected. Since *Xylia xylocarpa* is a fire tolerant species, the regeneration was not affected while regeneration of *Terminalia paniculata* was affected. During the survey it was observed that due to forest fire most of the undergrowth was affected (Plate 21-24). But, it was also observed that new regeneration was evident in few fire affected areas (Plate 26). The regeneration of tree species like *T. paniculata* and *T. tomentosa* needs protection and artificial regeneration with other indigenous species where site constraints hamper new growth.

In the burnt area, IVI of herbs and shrubs *Strobilanthes callosa* (101.53) tops the list followed by *Leea indica* (23.10) and *Ixora coccinea* (12.37) (Fig. 13). In the unburnt area, *Strobilanthes callosa* (82.46) tops the list followed by *Leea indica* (29.46) and *Ixora coccinea* (22.24). It can also be observed that in unburnt area the number of species were 13 while in burnt area was 11 and the dominance of single species (*S. callosa*) has increased in burnt areas.

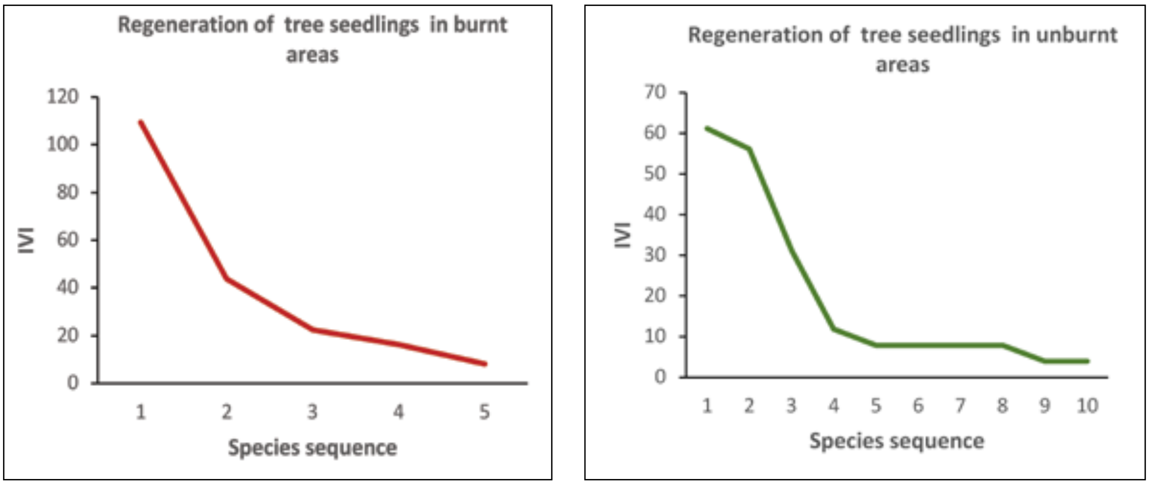


Fig. 12: Dominance diversity curve of regeneration of tree seedlings in burnt and unburnt areas in different forest divisions of Goa after the forest fire incidence of March-April, 2023

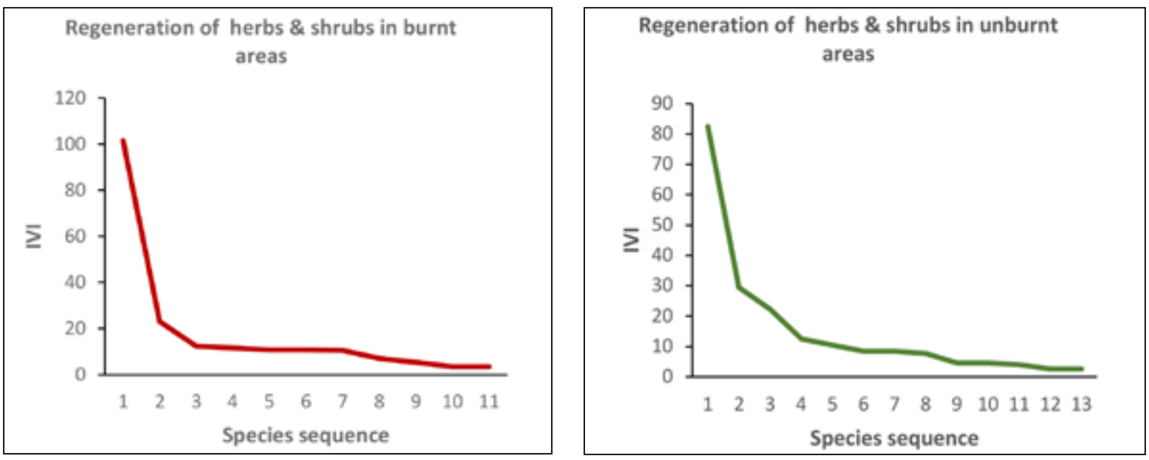


Fig. 13: Dominance diversity curve of regeneration of herbs and shrubs in burnt and unburnt areas in different forest divisions of Goa after the forest fire incidence of March-April, 2023

Status of litter in different forest locations

It was observed that, litter quantity collected in 1m x 1m quadrat was higher in unburnt areas compared to burnt areas (Table 14) clearly indicating that due to the forest surface fire most of the litter has been burnt. Litter is a crucial part of the nutrient cycle in forest ecosystems, which controls the buildup of soil organic matter (SOM), nutrient intake and outflow, nutrient replenishment, biodiversity preservation, and other ecosystem activities.

Table 14: Tree density (no.'s/ha) and litter quantities (kg/ha) available in different locations under two burn scenarios.

Site no.	Burnt areas		Unburnt areas		Forest type
	No. of trees/ha	Litter (kg/ha)	No. of trees/ha	Litter (kg/ha)	
1	400	733	600	7114	Deciduous forest
2	1900	2006	1400	5940	Deciduous forest
3	900	3062	1100	6151	Deciduous forest
4	500	1251	600	7049	Deciduous forest
5	600	2503	500	4275	Deciduous forest
6	500	2781	700	10221	Deciduous forest
7	800	1736	700	9515	Deciduous forest
8	800	2140	500	3830	Deciduous forest
9	700	1924	400	4825	Deciduous forest
10	600	2391	500	3279	Deciduous forest
11	600	2370	600	4806	Deciduous forest
12	600	2415	500	8099	Deciduous forest
13	500	2754	400	7870	Deciduous forest
14	400	1320	400	3302	Deciduous forest

Forest fire vulnerability mapping

From the analysis done and by field validation, distance from settlement and roads are identified as the two major factors causing the forest fire. The forest areas close to settlement or roads are more prone to fire due to campfires, thrown un-extinguished cigarette butts, match sticks, cooking near forests (Nikhil *et al.,* 2021) and intentional burning of dry grasses in the summer season for obtaining a new flush soon after the rains. Fires can be put intentionally or unintentionally by moving passengers and vehicles on the road (Veena *et al.,* 2017). The weights for fire conditioning factors and subclasses of each factor are given in Table 15 and 17. Based on the distance from the settlements, Goa was classified into five zones namely 0-500, 500-1000, 1000-1500, 1500-2000, > 2000 m (Fig. 14 a). Similarly, according to the distance from roads, the study area was classified into four classes viz. 0-750, 750-1500, 1500-3000, >3000 (Fig. 14 b). The highest fire incidences were recorded in first class of both distance from settlement and distance from road (Table 15). So, higher weights were assigned to 0-500 m and 0-750 m class for distance from the settlements and distance from roads, respectively with subsequent classes receiving lower weights (Table 17).

The forest cover map was re-classified into very dense forest (VDF), moderately dense forest (MDF), open forest (OF), scrub, mangroves (Fig. 14 c). The frequency analysis of fire occurrences revealed that most of the fires happened in MDF followed by OF. So, the highest weight was given to MDF followed by OF while mangrove received the lowest weight. Number of fires were comparatively less in VDF. The NDVI of the study area varied between -0.171 to 0.781 which was classified into five classes namely < 0, 0-0.2, 0.2-0.4, 0.4-0.6 and > 0.6 (Fig. 14 d). Most of the fire occurred in 0.4-0.6 class followed by > 0.6. Accordingly, the highest weight was assigned to 0.4-0.6 class through AHP. Land surface temperature (LST, °C) of the region ranged from 26.18 to 36.67 °C which was grouped into four classes i.e. 26-29, 29-32, 32-35 and > 35 °C (Fig. 14 e). The areas with higher LST may prone to forest fire because of greater heating and loss of moisture. Higher LST causes greater evaporation leading to lower vegetation moisture content making the vegetation more inflammable. Accordingly, higher LST classes received more weights.

The slope of the study area was grouped into six classes viz.<3, 3-5, 5-10, 10-15, 15-35, and >35% (Fig. 14 f). Equal weights were given to 10-15 and 15-35% slope class followed by 5-10, >35, 3-5 and <3%. Steeper slopes are drier due to more runoff and less storage of rainfall making it more prone to forest fires (Pradeep et al., 2022). Steeper slopes also hasten the upward movement of fire by creating local winds. The aspect was classified into eight classes as north (N), north east (NE), east (E), south east(SE), south (S), south west (SW), west (W) and north west (NW) (Fig. 14 g). Aspect influences forest fire by affecting the solar radiation received and soil moisture availability (Nikhil *et al.,* 2021). The western and southern aspects receive more solar radiation leading to more heating. So, more forest fire incidences occur on western and southern aspects. Topographic wetness index (TWI) indicates soil moisture distribution according to terrain (Kopecký *et al.,* 2021). The areas with higher TWI will have greater soil moisture leading to less forest fires. In the current study, Goa was divided into four zones namely < 10, 10-15, 15-20, >20 based on TWI (Fig. 14 h). The areas with higher altitude generally have lower temperature with less human interferences (Sun *et al.,* 2022). So, high altitude areas are considerably less likely to experience fires than the low altitude areas. Elevation of the area was divided into six classes viz. <50, 50-100, 100-150, 150-200, 200-500, >500 m (Fig. 14 i).

Table 15: Pair-wise comparison matrix of forest fire conditioning factors used for AHP

	Distance to settlements	Distance to road	Forest type	NDVI	Aspect	Slope	TWI	Elevation	LST	Weight
Distance to settlement (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	0.304
Distance to road (m)	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	0.215
Forest type	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	0.152
NDVI	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	0.107
Aspect	0.20	0.25	0.33	0.50	1.00	3.00	4.00	5.00	6.00	0.089
Slope	0.17	0.20	0.25	0.33	0.33	1.00	2.00	3.00	5.00	0.053
TWI	0.14	0.17	0.20	0.25	0.25	0.50	1.00	2.00	4.00	0.038
Elevation	0.13	0.14	0.17	0.20	0.20	0.33	0.50	1.00	2.00	0.025
LST	0.11	0.13	0.14	0.17	0.17	0.20	0.25	0.50	1.00	0.018

Consistency index (CI) = (λ_{max} - n)/(n - 1) = 0.128; Maximum Eigenvalue (λ_{max}) = 10.03

Random index (RI) = 1.45 for n = 9; Consistency ratio (CR) = CI/RI = 0.088

TWI – Topographic wetness index; LST – Land surface temperature; NDVI – Normalized Vegetation Index

Table 16: Area and frequency of forest fire under each subclass of forest fire conditioning factor.

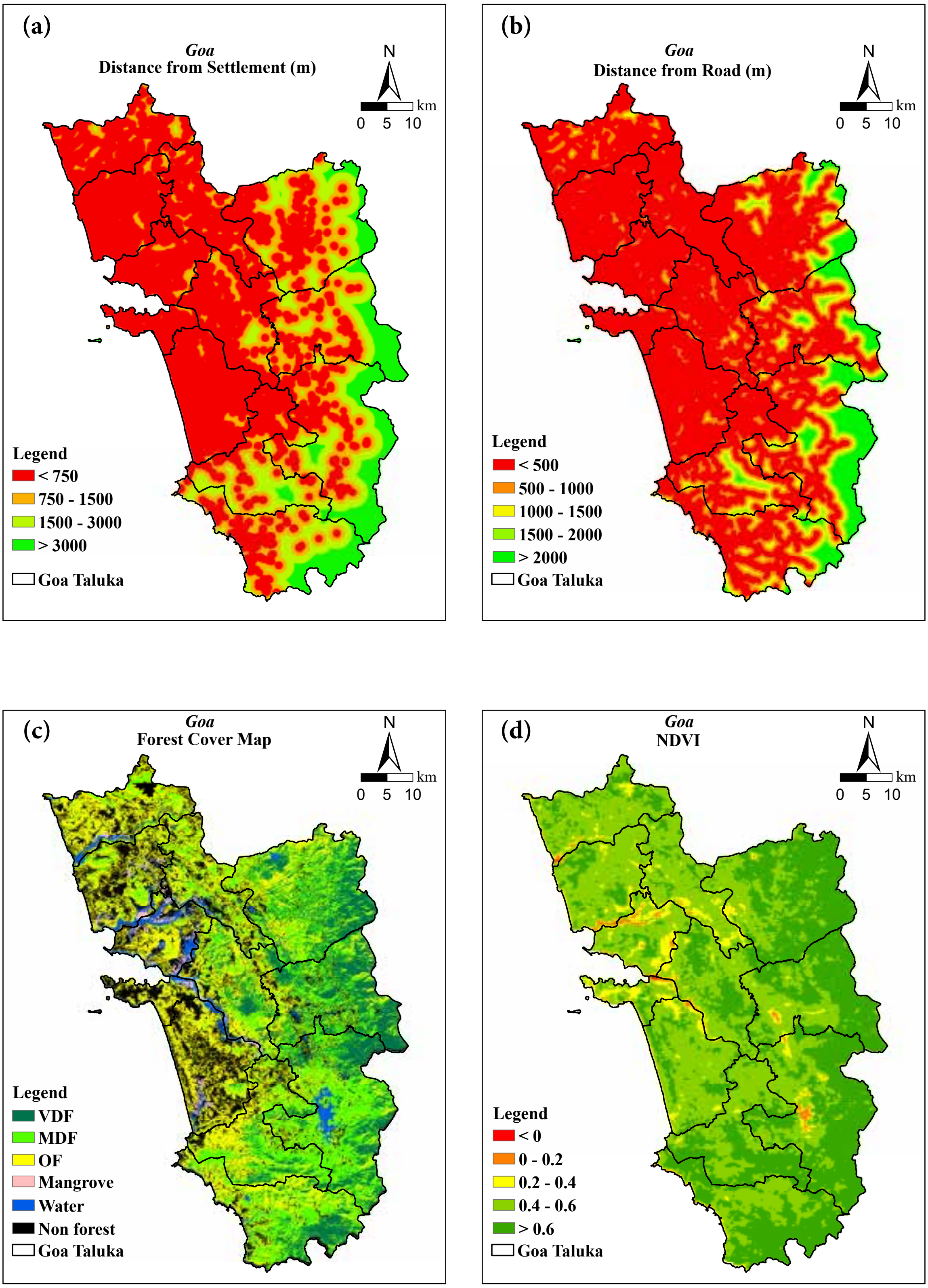
1. Distance to settlement	Frequency of forest fire	Area (ha)
< 750	68	216656.2
750-1500	53	67292.93
1500-3000	23	45986.96
> 3000	3	32086.46
2. Distance to road		
< 500	87	256189.8
500-1000	28	50127.46
1000-1500	16	21273.73
1500-2000	11	11773.15
> 2000	7	22658.47
3. Forest types		
VDF	15	58665.46
MDF	62	99122.35
OF	51	115146.9
Mangrove	0	4880.92
Water	2	14027.98
Non forest	17	69269.35
4. NDVI		
< 0	0	193.59
0.0-0.2	1	3220.98
0.2-0.4	0	19167.72
0.4-0.6	79	183745.2
> 0.6	67	154785.5
5. LST		
26-29	17	53487.35
29-32	107	187338
32-35	22	116327
>35	1	3960.712
6. Slope		
< 3	13	73157.37
3-5	15	36398.58
5-10	30	73383.81
10-15	38	47919.48
15-35	41	97326.33
> 35	10	32927.46
7. Aspect		
N (0-22.5)	10	44513.8
NE (22.5-67.5)	12	40901.47
E (67.5-112.5)	9	35071.72
SE (112.5-157.5)	22	37653.82

S (157.5-202.5)	27	43692.91
SW (202.5-247.5)	29	50387.29
W (247.5-292.5)	14	45276.37
NW (292.5-337.5)	15	42977.41
N (337.5-360)	9	20638.24
8. TWI		
< 10	131	292555.6
10-15	14	49235.89
15-20	2	17239.09
> 20	0	2082.458
9. Elevation		
<50	27	150958
50-100	64	97564.65
100-150	35	41670.33
150-200	7	18355.29
200-500	8	38640.03
>500	6	13924.77

Table 17: AHP weights of sub-criteria for forest fire conditioning factors.

1. Distance to road (m) CR = 0.046									
Class	0-500	500-1000	1000-1500	1500-2000	> 2000				Weight
0-500	1.00	1.00	3.00	7.00	9.00				0.39
500-1000	1.00	1.00	3.00	5.00	7.00				0.35
1000-1500	0.33	0.33	1.00	3.00	5.00				0.15
1500-2000	0.14	0.20	0.33	1.00	3.00				0.07
>2000	0.11	0.14	0.20	0.33	1.00				0.04
2. Distance to settlement (m) CR = 0.071									
Class	0-750	750-1500	1500-3000	>3000					
0-750	1.00	3.00	5.00	9.00					0.57
750-1500	0.33	1.00	3.00	7.00					0.27
1500-3000	0.20	0.33	1.00	3.00					0.11
>3000	0.11	0.14	0.33	1.00					0.05
3. Forest type CR = 0.022									
Class	MDF	OF	Scrub	VDF	Mangroves				
MDF	1.00	2.00	2.00	5.00	7.00				0.41
OF	0.50	1.00	1.00	3.00	5.00				0.23
Scrub	0.50	1.00	1.00	3.00	5.00				0.23
VDF	0.20	0.33	0.33	1.00	3.00				0.09
Mangroves	0.14	0.20	0.20	0.33	1.00				0.04

4. NDVI CR = 0.089									
Class	0.2-0.4	0.4-0.6	> 0.6	0-0.2	< 0				
0.2-0.4	1.00	3.00	5.00	9.00	9.00				0.53
0.4-0.6	0.33	1.00	3.00	5.00	5.00				0.24
> 0.6	0.20	0.33	1.00	3.00	3.00				0.12
0-0.2	0.11	0.20	0.33	1.00	3.00				0.07
< 0	0.11	0.20	0.33	0.33	1.00				0.04
5. Slope CR = 0.050									
Class	10-15	15-35	5-10	> 35	3-5	< 3			
10-15	1.00	1.00	3.00	5.00	7.00	9.00			0.34
15-35	1.00	1.00	3.00	5.00	7.00	9.00			0.34
5-10	0.33	0.33	1.00	3.00	5.00	7.00			0.17
> 35	0.20	0.20	0.33	1.00	2.00	4.00			0.08
3-5	0.14	0.14	0.20	0.50	1.00	2.00			0.04
< 3	0.11	0.11	0.14	0.25	0.50	1.00			0.03
6. Aspect CR = 0.085									
Class	SW	S	W	NW	SE	E	NE	N	
SW	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	0.32
S	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	0.22
W	0.33	0.50	1.00	2.00	3.00	5.00	6.00	7.00	0.16
NW	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00	0.10
SE	0.20	0.25	0.33	0.50	1.00	3.00	4.00	5.00	0.08
E	0.17	0.20	0.20	0.33	0.33	1.00	3.00	4.00	0.05
NE	0.14	0.17	0.17	0.25	0.25	0.33	1.00	2.00	0.03
N	0.13	0.14	0.14	0.20	0.20	0.25	0.50	1.00	0.02
7. LST CR = 0.082									
Class	> 35	32-35	29-32	26-29					
> 35	1.00	3.00	5.00	7.00					0.56
32-35	0.33	1.00	3.00	5.00					0.26
29-32	0.20	0.33	1.00	3.00					0.12
26-29	0.14	0.20	0.33	1.00					0.06
8. TWI CR = 0.069									
Class	< 10	10-15	15-20	>20					
< 10	1.00	2.00	5.00	9.00					0.53
10-15	0.50	1.00	3.00	7.00					0.31
15-20	0.20	0.33	1.00	2.00					0.10
>20	0.11	0.14	0.50	1.00					0.05
9. Elevation CR = 0.065									
Class	50-100	100-150	150-200	200-500	0-50	> 500			
50-100	1.00	1.00	3.00	5.00	7.00	9.00			0.36
100-150	1.00	1.00	2.00	3.00	5.00	7.00			0.28
150-200	0.33	0.50	1.00	3.00	5.00	7.00			0.19
200-500	0.20	0.33	0.33	1.00	3.00	4.00			0.10
0-50	0.14	0.20	0.20	0.33	1.00	2.00			0.05
> 500	0.11	0.14	0.14	0.25	0.50	1.00			0.03


(a)
Goa
Distance from Settlement (m)
N
km
0 5 10
Legend
< 750
750 - 1500
1500 - 3000
> 3000
Goa Taluka
(b)
Goa
Distance from Road (m)
N
km
0 5 10
Legend
< 500
500 - 1000
1000 - 1500
1500 - 2000
> 2000
Goa Taluka
(c)
Goa
Forest Cover Map
N
km
0 5 10
Legend
VDF
MDF
OF
Mangrove
Water
Non forest
Goa Taluka
(d)
Goa
NDVI
N
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< 0
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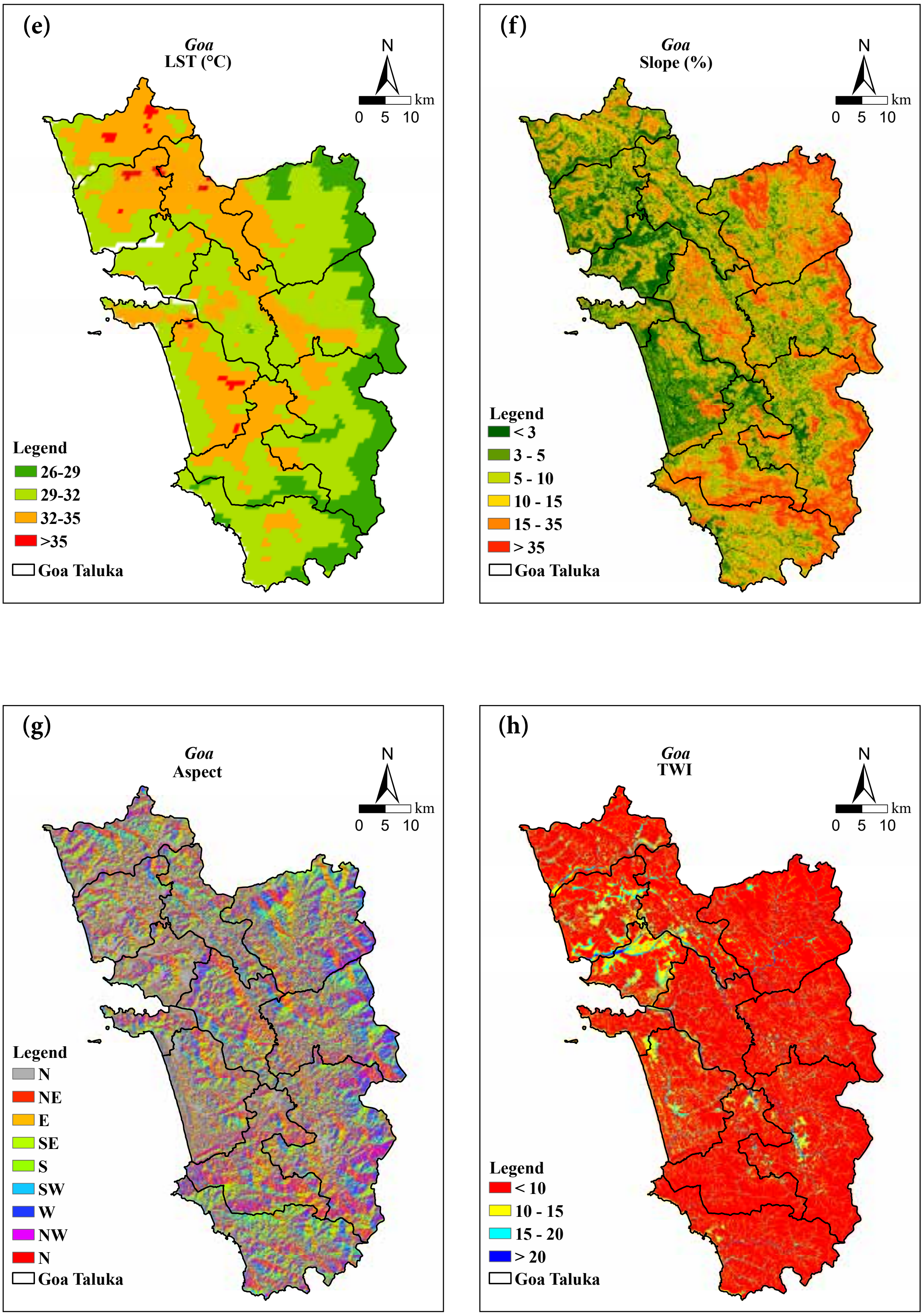
0.2 - 0.4
0.4 - 0.6
> 0.6
Goa Taluka


(e)
Goa
LST (°C)
N
km
0 5 10
Legend
26-29
29-32
32-35
>35
Goa Taluka
(f)
Goa
Slope (%)
N
km
0 5 10
Legend
< 3
3 - 5
5 - 10
10 - 15
15 - 35
> 35
Goa Taluka
(g)
Goa
Aspect
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km
0 5 10
Legend
N
NE
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S
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> 20
Goa Taluka

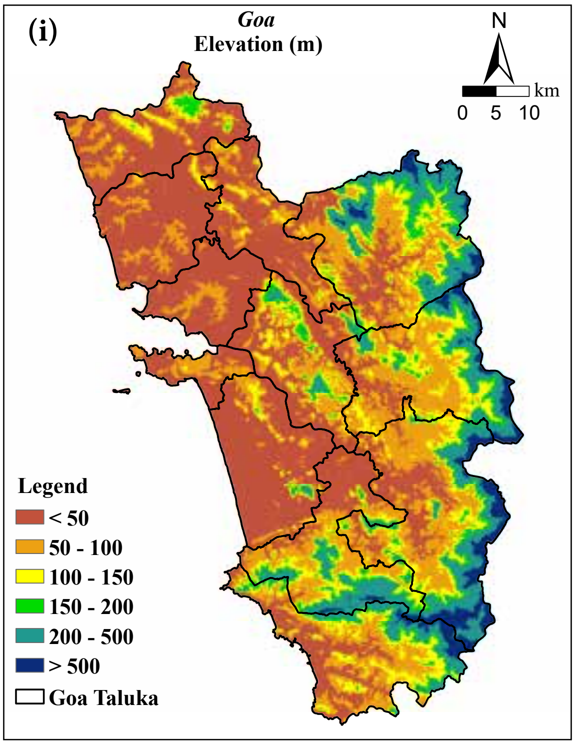

Fig. 14: The factors affecting forest fire vulnerability (a) distance from settlement, (b) distance from road, (c) forest types, (d) NDVI, (e) LST, (f) slope, (g) aspect, (h) TWI and (i) elevation.

Forest fire vulnerable zones

Through weighted overlay of forest fire conditioning factors, forest fire vulnerability map for Goa state was prepared (Fig. 15). The forest fire vulnerability was classified five classes using natural breaks as very low, low, moderate, high and very high (Table 18). The maximum area was estimated to be under very high vulnerable class (38.90%) followed by moderate (19.64%) and high (17.74%) class. Validation of forest fire vulnerability map was done through ROC curve with area under the curve was 0.963, indicating excellent performance (Fig. 16).

It is thus apparent that, large part of Goa's forest cover is now very highly vulnerable to forest fires and there is an urgent need to take adequate preventive measures. With infrastructure development taking place every year, more and more areas are now exposed to human induced disturbances which correspondingly increases forest vulnerability to fire. While there is very limited control over changing climatic (rainfall, temperature and number of rainy days) patterns, a certain level of preparedness is required at the ground level, which is implementable and effective. Public participation in protection of forests through trained village level participants can also be explored.

Table 18: Forest area in Goa under various forest fire vulnerability classes.

Class	Area (ha)	% area
Very low	28340.37	10.23
Low	37366.02	13.49
Moderate	54399.51	19.64
High	49158.63	17.74
Very high	107773.5	38.90
Non forest areas	84075.00	

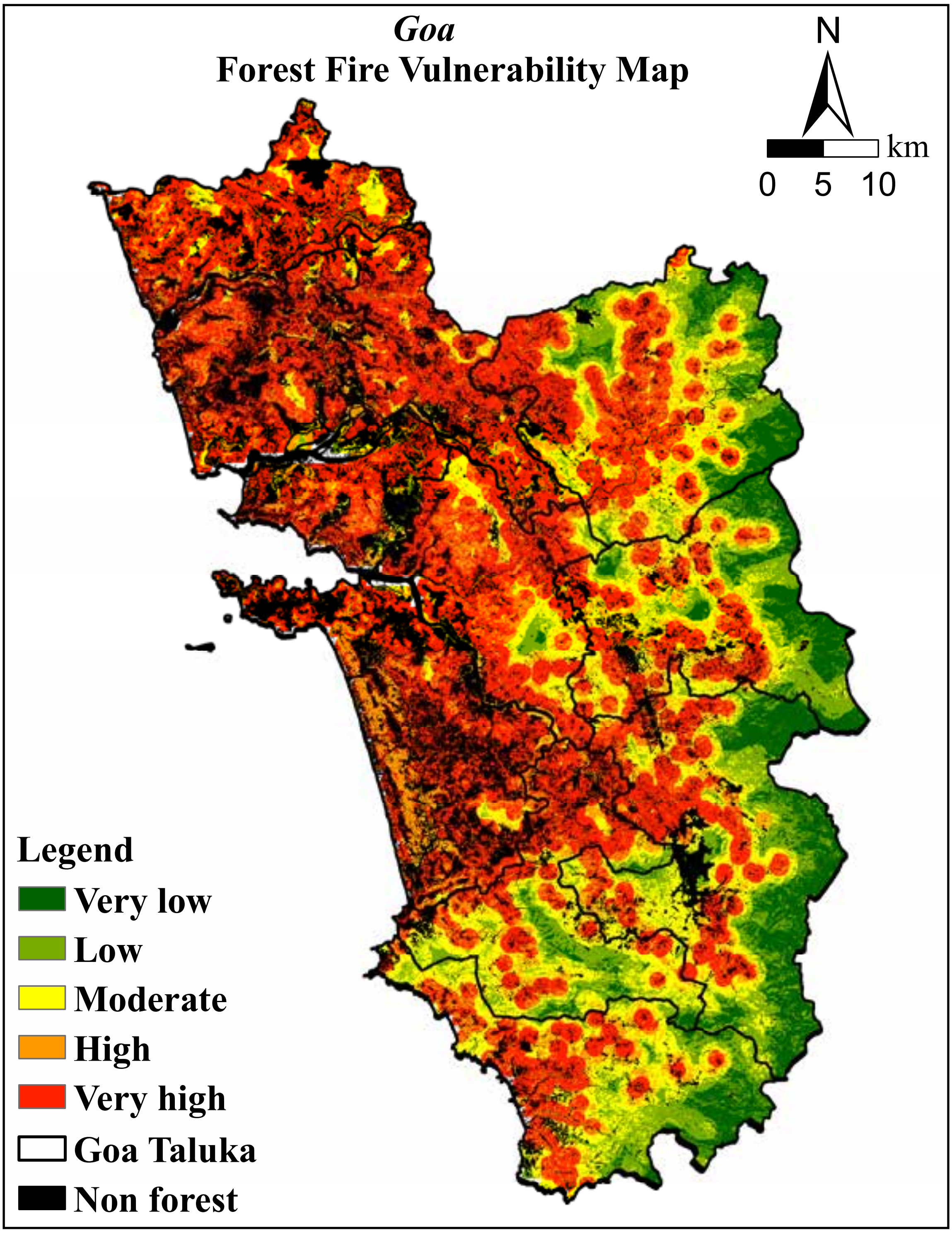

Fig. 15: Forest fire vulnerability map of Goa.

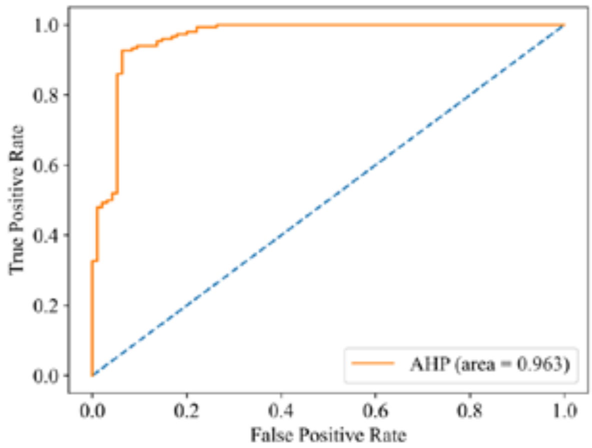

Fig. 16: ROC curve for the AHP-produced forest fire vulnerability map.

Validation of forest fire vulnerability map

The validation of the methodology followed to prepare the vulnerability map was verified with the subsequent fire incidents which occurred during late March and April, 2023 in the forests of Goa (Fig. 17). Out of 127 fire points during 2023, 64 points were recorded in the high to very high fire vulnerability class while 36 points were observed in the moderate fire vulnerability class. Only 7 points were observed in the very low fire vulnerability class. The AUC for March and April, 2023 was reported to be 0.946 which was very close to our previous year validation. So, the methodology developed for forest fire vulnerability mapping is efficient in identifying fire prone areas in Goa.

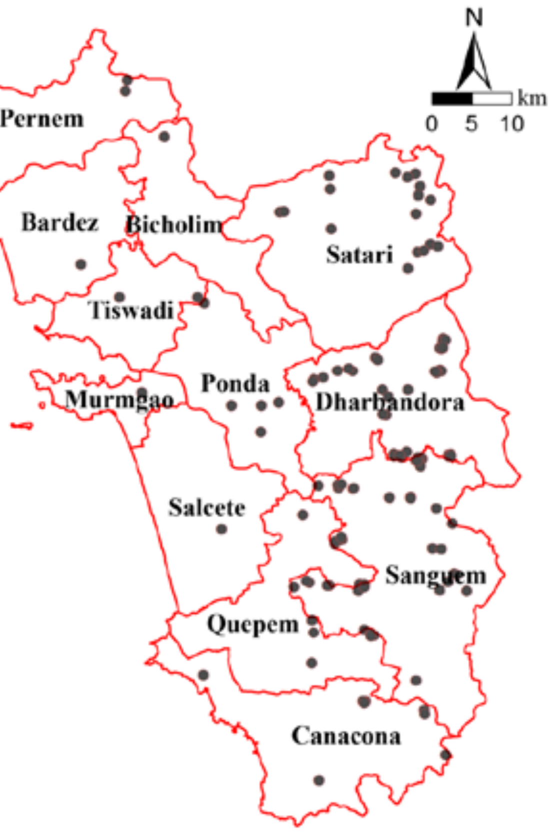

Fig. 17: Forest fire location between March to April, 2023 in state of Goa

Mitigation strategies for forest fire control

In view of the large extent of fire in the state and the long term implication of fires on the forest cover, ecosystem resilience and the vulnerability of the Western Ghats to the ongoing climate change events, a number of mitigation measures are being recommended which are required to be undertaken to prevent the large scale occurrence of forest fires in the state. These are briefly described below

A) Mechanical measures to be undertaken –

- There is an urgent need to adopt a combination of contour and staggered trenches in sloping forest areas which will lead to *in-situ* soil and water conservation, reduce run off, provide infiltration time, enhance soil moisture availability and encourage quick establishment and growth of seedlings and saplings.
- Trenches of size – 1 to 1.5 m long, 30 cm wide and 30 cm deep need to be manually excavated at a uniform distance of 2-3 m wherever possible, keeping in mind that most soils in forests are shallow to very shallow. A study reported by Sumbali *et al.,* (2012) from Uttar Kannada (Karnataka) in a plantation of *Acacia auriculiformis,* raised on 6% slopes indicated that that there was significantly higher soil moisture content at depth of 0-30 and 30-60 cm in plots with continuous contour trenches as compared to control and led to improved growth of plants.
- These *in-situ* moisture conservation practices also need to be undertaken in private forest areas, presently under cashew cultivation, to encourage better establishment and growth of cashew plants, which were observed to be under stress due to the long hot and dry season for the last six months.
- There is a need to establish shallow lined dug out ponds (0.7m deep) in the lower reaches which can serve as watering points for wildlife and also as a water source in times of emergencies. In other areas, similar dug out ponds can be excavated which will store run off water in the post-monsoon season for about 2-3 months. These dug out ponds also need to be periodically cleaned.
- Formation of steep gullies due to flow of water was noticed in areas with undulating terrain and there is an urgent need to put up wired gabion structures in the first and second order steams to reduce velocity of flowing water and help in soil retention.
- Undertake controlled burning in highly vulnerable areas (with adequate protection measures) to prevent re-occurrence of fire due to the thick accumulation of leaf litter on the surface in most areas before the onset of the summer season.
- Establish and maintain fire lines in internal (compartment level) and external (on the boundaries) on a regular basis
- Establish water storage tanks in the buffer zones with easy access for tankers.
- Establish at each forest outpost a set (4-6 no.'s) of sand filled buckets for immediate control of surface fires.

B) Biological measures to be undertaken –

Monocultures of *Acacia auriculiformis* were abundant, in the areas developed by the social forestry division where surveys were undertaken, with a thick layer of undecomposed dry litter on the forest/plantation floor. Lack of soil moisture was clearly evident with some seedlings in the wilting stage and poor regeneration. *A. auriculiformis* is not native to this region, it is a moderately fire resistant species, unpalatable and has been a preferred species for planting in afforestation activities. However, studies have indicated that the dry litter burns rapidly due to a waxy coating on the leaves, making surface fires in *A. auriculiformis* plantations common. It is suggested that –

- *In-situ* moisture conservation activities be undertaken in these plantations to allow for rapid litter breakdown and decomposition so that soil nutrient quality is improved.
- Establishment of mixed plantations of native species should be undertaken along with soil and water conservation activities which will allow secondary growth of desired species and their successful establishment.
- Current plantation density is low (800 seedlings/ha) which can be easily increased to 1500 seedlings/ha, along with suitable moisture conservation practices, since there is abundant rainfall for four months; pitting done by April end and planting by the end of June is a suitable time frame for planting & afforestation.
- There is an urgent need to take up trench-cum-pit planting of native species in the burnt areas so that quick establishment takes place in the ensuing monsoon season.
- Since it has been reported that fire is also used to encourage sprouting of grasses in forest areas, it is suggested that fodder banks of fodder grasses, be established in and around the vicinity of inhabitations in close proximity to forest areas, so that farmers do not have to go to forest areas for harvesting grasses for their animals. Rooted slips of fodder grasses may be supplied to farmer groups which will be used to establish fodder resources in the village.
- Incidence of termites is wide spread in the deciduous forests which make the trees vulnerable to strong winds, disease and fire; there is an urgent need to take up termite control measures in the affected areas by chemical and mechanical means.

C) Administrative measures to be undertaken –

Forests in Goa are spread over undulating terrain, ranging right from river banks (of Zuari, Mandovi,) to hills of the Mahadei sanctuary and beyond. It therefore becomes necessary that measures must be in place to watch over the large area consisting of very dense forests in protected areas to open forests close to human habitation. Some measures which need to be undertaken at the earliest are mentioned below:

- The number of watch towers have to be significantly increased which must be used intensively during the summer months. At present the density of watch towers is very low (For example, in the Mahadei sanctuary spread over 208.48 ha of undulating terrain, there are only two watch towers) which has to be increased, especially in those areas which are prone to forest fires.
- Create public awareness of "damage caused by fire" by the use of boards and hoardings in villages, along highways, schools and settlements.

- Increase the use of media (print & electronic) to create awareness about forest fire and its consequences during the summer season.
- Occurrence of forest fire should be recorded by mentioning date, month, compartment, block with GPS co-ordinates, so that gap filling and protection is quickly taken up in the affected areas.
- Provide fire extinguishers at all forest outposts, range offices and nearby settlements for control of fire plus all other necessary firefighting equipment.
- Provide 4x4 drive vehicles and motor cycles in vulnerable blocks/ divisions, fully equipped with firefighting equipment, trained staff and communication systems
- The use of drones for monitoring forest areas and forest fires needs to be pursued and suitable drones with trained pilots need to be acquired for effective forest protection.
- Explore the possibility of convergence of various central and state schemes (for example MGNREGA) for implementing water conservation practices which will benefit wildlife and forest vegetation.

D) Capacity building measures to be undertaken –

Sensitizing human resources for forest management and forest protection is a neglected subject in the country and there is an urgent need to relook into the idea of 'stand alone' practices of forest management, given the large rural population depending on forest resources for various products. The following are suggested-

- Undertake capacity building of forest personnel in control of fire, use of firefighting equipment, establishment and maintenance of fire lines etc.,
- Undertake the capacity building of cultivators in the private forests to prevent forest fires and provide them with basic firefighting equipment.
- Develop a dedicated team of trained staff who would implement soil and water conservation practices in forest areas and demarcated forest land for effective natural resource conservation.
- Undertake training of farm women in establishment and management of fodder banks raised in and around the villages, which will act as a source of fodder for their animals and discourage them to burn/harvest grasses from forest areas. These trainings can be arranged in collaboration with the state agriculture department which will also provide grass slips for planting.

E) Legal measures to be undertaken-

Since Goa has a significant area (46.11 sq.km) under private forests, it is necessary that effective forest management practices be undertaken in these areas, both for the benefit of the cultivator and also to maintain ecosystem stability in the ecologically sensitive Western Ghats. The following measures are suggested –

- Under the amended Goa Land Revenue (Record of Rights & register of cultivators) (Amendment) Rules, 2022, identify the owners/cultivators of the private forests and using RS & GIS techniques, geotag the selected area with an identity number, mention actual area, species being grown etc.,

- Display the list of the cultivators in the nearest range office along with contact numbers, which is presently limited to only survey numbers in different villages (Annexure I).
- Explore the potential of providing 'carbon credits' to cultivators who properly manage their plantation and are able to demonstrate this in the field.
- Develop a mechanism for regular management of private forests including disease and pest control on a cost sharing basis with cultivators, since cashew cultivation is a commercial enterprise and the cultivator should invest some percentage of the earnings in activities to sustain the plantation.

Advance tools

In recent years, advance tools and technologies have been developed to fight forest fires in India. Here are some of the advanced tools used to fight forest fires:

- Unmanned Aerial Vehicles (UAVs): UAVs or drones are used to survey the affected areas and provide real-time information about the fire's extent and direction. They can also be used to drop water and fire retardants on the fire from a safe distance.
- Satellite-based fire detection: Through satellite systems we can get near-real-time information on forest fires. This enables the authorities to quickly identify and respond to forest fires.
- Geographic Information System (GIS): GIS is used to map the fire's extent and intensity, identify the vulnerable areas, and help firefighters plan their operations. GIS data can also be used to predict the spread of the fire and plan evacuation measures.
- Thermal Imaging Cameras: Thermal imaging cameras can detect hotspots in the forest and help firefighters target their efforts more effectively. They can also be used to monitor the fire's progress and identify areas that are at risk of ignition.
- Fire Retardants: Fire retardants are chemicals that can be used to slow down or stop the spread of a forest fire. They are sprayed from aircraft or ground-based vehicles and can help protect structures and prevent the fire from spreading.
- Fire Shelters: Fire shelters are portable, lightweight shelters that can protect firefighters from the heat and flames of a forest fire. They are made of fire-resistant materials and can be deployed quickly in an emergency.
- Firefighting Aircraft: Aircraft such as helicopters and planes are used to drop water and fire retardants on the fire from above. They can also be used to transport firefighting crews and equipment to remote locations.
- Fire Extinguishers: Portable fire extinguishers can be used by firefighters on the ground to control small fires or prevent them from spreading.

Overall, the use of advance tools and technologies can help to improve the effectiveness and efficiency of firefighting operations in India. By investing in these tools and technologies, the authorities can help to protect the environment, wildlife, and human lives from the devastating effects of forest fires.

Conclusion

The management of forest fires in Goa involves a coordinated and multi-faceted approach that focuses on prevention, detection, suppression, and rehabilitation. By implementing these measures effectively, the authorities can help to minimize the impact of forest fires on the environment, wildlife, and human lives and property.

- Prevention: The first step in managing forest fires is to prevent them from occurring in the first place. This can be done by creating fire breaks, removing dry vegetation, controlling human activities such as smoking and burning of agricultural fields, and educating the local communities and stakeholders about the risks and impacts of forest fires.
- Early detection: The timely detection of forest fires is crucial in preventing their spread and minimizing their impact. This can be done through the use of fire towers, patrols, and other monitoring systems. In addition, the public can be encouraged to report any signs of smoke or fire in the forest areas to the authorities.
- Suppression: Once a forest fire is detected, the authorities must take immediate action to suppress it. This involves deploying firefighting teams, helicopters, and other equipment to contain and extinguish the fire. The suppression efforts should be coordinated by the Forest Department in collaboration with the local administration and other stakeholders.
- Rehabilitation: After the forest fire is suppressed, the damaged vegetation and ecosystem need to be rehabilitated. This involves planting new trees, restoring the soil, and promoting the natural regeneration of the forest. The rehabilitation efforts also provide an opportunity to enhance the resilience of the forest ecosystem and reduce the risk of future fires.

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Appendix - I

Distribution of private forests in different Talukas and number of villages*

Sl. No.	Taluka	No. of Villages
1	Sanguem	18
2	Canacona	4
3	Salcete	5
4	Quepem	11
5	Marmagao	1
6	Tiswadi	9
7	Bicholim	1
8	Dharbandora	10
9	Ponda	5
10	Saltari	10
11	Bardez	16
12	Pernem	3
	Total	93

*The actual number of cultivators and area (acres/hectares) in each village is not known.

Source: Gazette notification of 13.9.22; No.55/DCF(WP)/Court Case/SC/2021-22/Part File/FD/167.

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