A REVIEW OF INDIA SCALE ANALYSIS OF FOREST FIRE AND TOXIC EMISSION

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ABSTRACT:

Forest is like a backbone to live on earth. Humans are dependent on it for food, shelter, and habitat. Exponentially increasing human population is making pressure on forests and their ecosystem. Although we are greatly dependent on the forest for our day-to-day life still there is the least effort evident from the human side for its conservation. Forest fire is a natural phenomenon that occurs due to various natural causes. With increasing population pressure, humans are trying to develop their habitat leading to patches within the forest. Forest fire is one of the easiest ways of clearing forest cover. The careless activity of humans and lack of a proper management system is making forest fire a threat to human civilization. According to a Forest Survey of India Report, about 50 percent of forest areas in the country are fire-prone (ranging from 50 percent in some states to 90 percent in the others) and about 6 percent of the forests are prone to severe fire damage. In this study it is summarised that in India forest fire occurrence is mostly seen during summer that is in between February - May and the most affected forest type is tropical deciduous forest which is found in Odisha, Chhattisgarh, Bihar, Telangana, Andhra Pradesh, Jharkhand, and West Bengal states of India. As the forest fire rate is very frequent in India, we should plan a proper strategy to control forest fire with the help of previous forest fire data available in some research papers and remote sensing data to be used to prepare nationwide fire history maps for better formulation of forest fire control measures to minimize the intensity and spread. Keywords: Forest fire, India, human civilization.

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INTRODUCTION:

Forest is defined as a community of interacting species, organized by *structural* elements and species *composition* that perform specific *functions.* The structure here refers to the physical aspects of a forest, such as an overstory canopy. It is an area that protects and balances the natural ecosystem. Forest is a type of ecosystem that majorly includes flora and fauna interacting with each other and their environment. Forests dominate the natural landscape over much of the world and those forests harbor a large proportion of the world's species. Moreover, as forests are valuable to humans for the products and services that they provide – especially wood – many forest ecosystems are extensively manipulated and modified by human societies, often disrupting the natural ecological patterns. Notably, from a structural standpoint, trees can be alive or dead and standing or down. Some forests, such as mature (> 80 years) Douglas-fir (*Pseudotsuga menziesii*) western hemlock (*Tsuga heterophylla*) in the Pacific Northwest are comprised of a continuous, multi-layered canopy from the ground up—shrubs, lower, mid, and overstory strata. A native forest has all the parts working together—structure (all age classes especially older), composition (the natives), and function (e.g., natural disturbances, food-web dynamics). It should be noted that a forest is not just a collection of plants. The animals codesign the fundamental elements.

How forest ecology works?

The forest is made up of trees, plants, and animals that together make up a complicated and productive system. The plants and trees take water and minerals from the ground, carbon dioxide from the air, and energy from the sunlight to grow, producing more and more plant material (leaves, wood, roots) as they do so. Many animals and insects feed on the plants or the dead materials they leave behind. Finally, mold and microbes (bacteria) eat what is left and return the minerals to the soil. Thus, all the life in the forest depends on the trees; if they are gone, much less food will be produced for everything else and the system will be less productive. The trees also shelter and protect the other life in the forest. When a forest tree dies or falls over, its place is quickly taken by young trees or tree seeds waiting underneath. Some trees are better at growing quickly in open areas where there is sunlight, filling in any gaps in the forest. Others may grow more slowly, but they

often grow taller and eventually dominate the other forest trees. Many trees depend on birds and insects in the forest for their reproduction. Bees, moths or other insects go from tree to tree fertilizing the flowers. Birds, bats or other animals that feed on tree fruits may also carry the seeds away from the parent tree to places where the young trees will have a better chance to grow. If the insects are killed by pesticides, or the birds are all shot by hunters, some trees may gradually disappear from the forest because fewer young ones will grow up to replace the old ones.

This is why a forest is called an ecosystem because each part helps the others and also depends on the others. If something hurts any part of the system, the other parts will also be affected.

Significance of forest in our life: The forest brings many benefits to the land and its people. In many ways, it is the forest that made the land into a place where people can live.

The forest changes lifeless rock into a living ecosystem. Over thousands of years, the plants and animals of the forest establish themselves and build a living cover of green. The forest grew slowly. A newly exposed area of land will first be colonized by a few plants which were very strong and could live on bare rock. Slowly other plants and animals followed. The forest which covers the land today maybe thousands of years old.

The forest makes the soil. The soil on the land is the old broken-down rock mixed with the dead plants of the forest and the many small animals and bacteria and plants which live in the soil. Forests made most of the soil on the planet. The forest protects the soil. It holds the soil with its roots. If the trees are cut down and no gardens are planted the soil gets hard and dry and not good for gardens. If heavy rains come and there are no trees, the soil gets muddy and washes away, polluting streams, rivers, and the sea. Then the soil is gone and gardens will not grow on the hard rock.

The forest shelters the gardens. When strong winds and heavy rains come the trees protect the gardens. Strong winds can hurt crops and dry out the soil. Near the coast, salt spray can poison the soil or harm the crops without the shelter of trees.

The forest holds water. The trees and the soil they make are full of water and they store this water for times of no rain. The forest controls the flow of water over the land. When heavy rains come the trees help trap the water in the soil. They hold water in their branches, trunks, roots, and leaves.

The forest makes clouds and rain. When the wind blows over the land it moves through the trees and the trees put water into the wind. When the wind goes through the trees, the trees also put excess heat from the sun into the wind. The heated, wet air then lifts up because hot air rises. When the hot, wet air hits the cooler wind above the land, it becomes clouds.

The forest controls garden pests. Inside the forest, many insects and birds, and animals live in a balanced system. When the balance is good, the life systems work together and there are not too many of any kind of plant or animal, or insect. Many of these animals and insects eat garden pests and mosquitos. When the forest dies the natural balance is lost and many of the good animals and insects disappear. In this way, mosquitos and diseases can increase and gardens can be attacked by pests if the forest.

The forest provides wood for people to use in making homes, tools, boats, carvings, and fuel for cooking. If the forests are cut the people will have to import wood for these needs at a cost many times the money they may now be paid for the same wood.

The forest has many plants which may be of great economic value. Not just trees, but foods, spices, and medicines grow in the forest.

The forest is the heritage of the local people. Treated with love and respect it will last forever and supply the people's needs. Many people have sacred ties to the trees and the forest that are part of their traditional cultures and are still important to them today. Lastly forests can prevent fires. When the forest is dead (dried trees, wood, and leaves) the land becomes dry and can quickly catch on fire and burn away all the life.

Forest Fire:

Fires are a part of the earth system from the pre-human era. They play a vital role in ecosystem composition and distribution (Bond and Keeley, 2005). Fires have been observed from the geological scale going back to the origin of terrestrial life (Bowman et al., 2009). The forest fire is usually only observed when it has already spread over a large area, making its control and stoppage arduous and even impossible at times.

Forest fires are considered as one of the most widespread hazards in a forested landscape. They have a serious threat to forest and its flora and fauna. Unplanned and abrupt forest fires are a major cause of forest degradation, while a controlled fire to manage and check the spread of unwanted forest fires serves as the action to improve the forest. There are several tangibles as well as intangible losses due to forest fires, and they cause an environmental threat to the affected area (kumar et al., 2021).

Fire ecology explores the interactions between fire and the surrounding environment, including both living and non-living things. Fire ecologists recognize that fire is a natural process that is often integral to the life history of plants and animals in the ecosystem. Station scientists study fire effects on ecosystems, fire history, how plants and animals depend on or adapt to fire, and fire regimes. A “fire regime” refers to the general pattern of wildfire’s natural occurrence in a particular ecosystem, including fire frequency, intensity, size, pattern, season, and severity as shown in fig. 1.

Causes of a forest fire:

Fires are considered to be a potential hazard having physical, biological, ecological, and environmental consequences and one of the major drivers of the global change in terrestrial ecosystems (Rudel et al. 2005)A forest fire can be caused via two major sources, natural and anthropogenic.

Natural cause: The forest fire caused by natural sources can be due to lightning, extreme rise in the temperature, subsequent spark produced, and volcanic explosion. High atmospheric temperatures and dryness (low humidity) of favorable circumstances for a fire to start (Jhariya and Raj, 2014; Satendra and Kaushik, 2014;

Juarez-Orozco et al., 2017). Wildfire occurs naturally in areas filled with trees, dry and parching wood, leaves, all these elements form a highly combustible material and represent the perfect context for initial-fire ignition and act as fuel for later stages of the fire.

Anthropogenic cause: In Indian Country, arson and debris burning are the leading causes of wildfires in areas where vegetation interfaces with urban structures. On average, human-caused wildfires account for 80% of all wildfires that occur in India every year. Due to their proximity to homes and other community infrastructure, they also destroy nearly 190 structures annually.

The major causes of forest fire or wildfire lightning, camp fire, smoking of cigarettes, fireworks, debris and arson burning and many more.

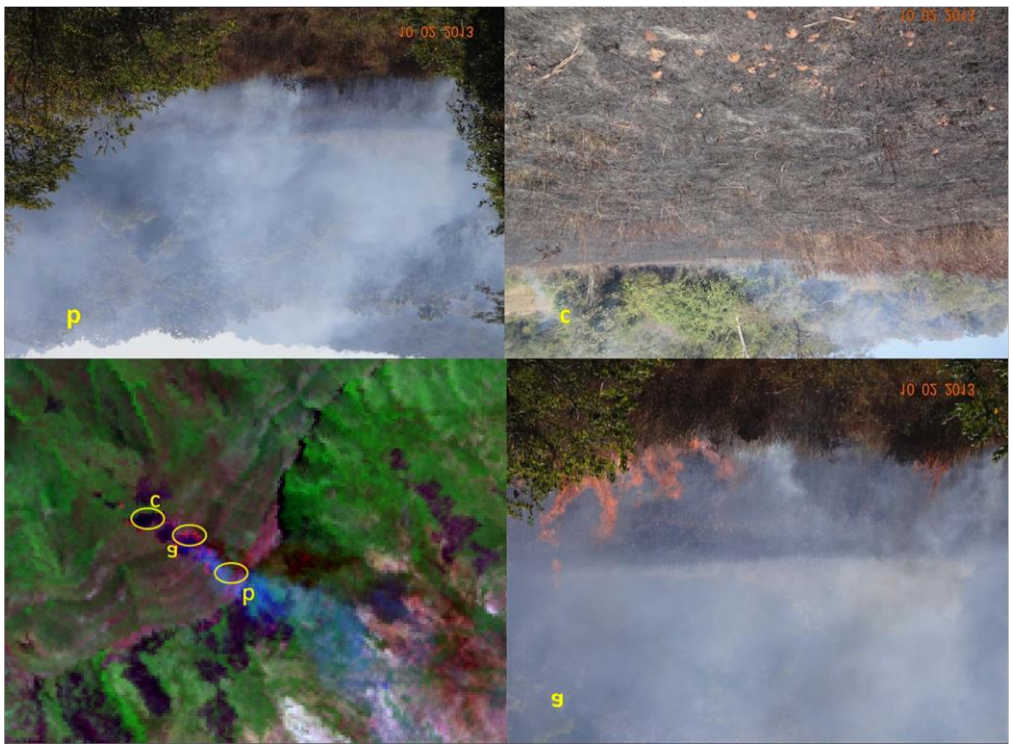

Fig.1. Image showing forest fire in AWiFS Satellite data and fire events. (Saranya et al., 2016)

Types of Forest Fire:

Forest fires are not always the same, they may differ, depending upon their nature, size, spreading speed, behavior, etc. Basically, forest fires can be sub-grouped into four types depending upon their nature and size –

Underground fires: The fires of low intensity, consuming the organic matter beneath, and the surface litter of the forest floor is sub-grouped as underground fires. In most dense forests, a thick mantle of organic matter is found on top of the mineral soil. This fire spreads by consuming such material. These fires usually spread entirely underground and burn for some meters below the surface. This fire spreads very slowly and in most cases, it becomes very hard to detect and control such types of fires. It may continue to burn for months and destroy the vegetative cover of the soil.

- The other terminology for this type of fire is Muck fires.

Ground fires: There is no clear distinction between underground and ground fires.

- The smoldering underground fire sometime changes into the ground fire. This fire burns roots and other material on or beneath the surface i.e. burns the herbaceous growth on the forest floor together with the layer of organic matter in various stages of decay. They are more damaging than surface fires, as they can destroy vegetation completely. These fires are often hard to detect and are the least spectacular and slowest moving. Fighting such fire is very difficult.

Surface fires: Surface fire is the most common forest fire that burns undergrowth and dead material along the floor of the forest. It is the type of fire that burns surface litter, other loose debris of the forest floor, and small vegetation. In general, it is very useful for forest growth and regeneration.

- But if grown in size, this fire not only burns ground flora but also engulfs the undergrowth and the middle story of the forest.
- Crown fires: Crown fire is the most unpredictable fires that burn the top of trees and spread rapidly by the wind. In most cases, these fires are invariably ignited by surface fires. This is one of the most spectacular kinds of forest fires which usually advance from top to down of trees or shrubs, more or less interdependent on surface fires. In dense conifer stands with a brisk wind, the crown fire may race ahead of the supporting surface fire. Since it is over the heads of ground force it is uncontrollable until it again drops to the ground, and since it is usually fast-moving, it poses grave danger to the firefighters becoming trapped and burned.

Fig.2. Image representing types of forest fires (Credit: Government of Ontario, https://twitter.com/ONforestfires/status/1102634466831409153?s=20)

Forest fire recorded globally:

- Every year, there are at least 50,000 fires in the Mediterranean region where 700,000 to 1 million ha of forest fall prey to the flames. This corresponds to 1.7 % of the entire forest cover of this region (FAO 2015). The forest fires in Mediterranean countries are almost exclusively human-induced - be it by accident or intentionally. The EU countries Spain, Portugal, Italy, and Greece are particularly affected. In Greece for example, over 1.4 million ha of forests were destroyed by fire from 1985 to 2014, which is more than one-tenth of the country's territory.
- Forests in the USA cover an area of 310 million ha, which is 31 % of the country's territory (FAO 2015). In the 1990s annual average forest cover loss increased to 1.3 million ha. Between 2000 and 2009, the annual burn area rose to 2.8 million ha. Between 2008 and 2010 forest cover loss values significantly decreased again, reaching 1.3 million ha in 2010, the lowest figure since the new millennium. 2015 was one of the worst forest fire years in the history of the USA. 68,151 fires burned an area of 4.1 million ha, the highest forest cover loss figure since the beginning of records. Since 1960 there have only been four years in which more than 9 million acres (3.6 million ha) burned, and all of these (2006, 2007, 2012, and 2015) were within the last 10 years.

- 34 % of Canada's national territory, or 347 million ha, is covered with forest (FAO 2015). In many forest ecosystems in Canada, fires are a natural process. In Canada's forests, there were on average 7,084 forest fires per year between 2004 and 2013. average forest cover loss was slightly below 2.3 million ha. In 2014, wildfire incidence at 5,126 was considerably below this average, while the burned area (4.6 million ha) was twice as high as the previous decade's average.
- 225 of the 429 forest fires in Germany in 2014 (over 50 %) occurred in East German federal states, although their share of Germany's forest cover is only 28 %. Their wood being rich in essential oils and resins, pine forests are particularly prone to fire. Most forest fires are human-induced. Forest fires caused by old ammunition and unexploded bombs in military training areas in hot and dry weather are officially responsible 2014 was the year with the lowest number of forest fires (429) and the lowest affected area (120 ha) since 1977 when statistical records started. With respect to the ten years average of the previous decade, fire incidence decreased by 41 %, while the affected area decreased by 63 %. Annual economic damage between 1991 and 2014 averaged 1.9 million euros. for 11 % of the fires in 2014.

Russia, as the largest country on Earth, boasts the largest forest cover of 815 million ha (FAO 2015). According to conservative estimates, 11 million ha of forests were lost within the last 5 years alone, between 2010 and 2014. 72 % of forest fires in Russia are caused by carelessness or arson. 7 % are provoked by the use of fire in agriculture.

- 14 % originate from other causes like sparks flying from power or railway lines. Lightning only causes 7 % of forest fires, although in the sparsely populated areas in northern Russia, the proportion of fires caused by lightning lies around 50–70 % (FAO 2006).

Forest fire study over Indian context:

India constitutes one of the mega bio-diversity zones of the world, abundant with unique and diversified floral and faunal wealth. The total Recorded Forest area of the country is 7,64,566 square kilometers. Due to increasing population pressure, this exemplary land ecosystem of the world is struggling for its survival. Increasing human interference in the natural forest ecosystem has also tremendously increased forest fire incidences. Every year one or other part of the forests in India comes under fire, Though the forest fire season throughout the country is not the same. Depending upon

the type of vegetation, the climate, and various other factors, the fire season varies from place to place. Though the major forest fire season in the country varies from February to June, some forests are not safe from fires throughout the year. A number of 37,059 fires were detected in the year 2018 using MODIS (Moderate Resolution Imaging Spectro-radiometer) sensor data. Every year large areas of forests are affected by fires of varying intensity and extent. Based on the forest inventory records, 54.40% of forests in India are exposed to occasional fires, 7.49% to moderately frequent fires, and 2.405 to high incidence levels while 35.71% of India's forests have not yet been exposed to fires of any real significance (FSI).

Forest fire spreading over a large forest area in the country causes immense loss to the environment and the property. As per the information available in answer to the Lok Sabha question, the Forest Survey of India does not report the number of forest fire incidences on the ground. It only disseminates the satellite-based forest fire alerts to all the State Forest Departments and other registered users. The information regarding the area affected in hectares and the loss in terms of money due to forest fire are not maintained at the level of the Central Ministry.

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Sl no.	States	Forest area (FSI 2013)	Forest burnt area (2014)	Burnt area percentage
1.	Odisha	50,347	8186.46	16.26
2.	Andhra Pradesh	25,999	6611.68	25.43
3.	Maharashtra	50,632	5066.66	10.01
4.	Chhattisgarh	55,621	4606.69	8.28
5.	Tamil Nadu	23,844	4275.65	17.93
6.	Madhya Pradesh	77,522	3342.66	4.31
7.	Telangana	20,117	2955.23	14.69
8.	Jharkhand	23,473	2587.40	11.02
9.	Manipur	16,990	1974.23	11.26
10.	Karnataka	36,132	1920.35	5.31
11.	Bihar	7291	1773.22	24.32
12.	Nagaland	13,044	975.79	7.48
13.	Assam	27,671	941.11	3.40
14.	Tripura	7866	739	9.39
15.	Gujarat	14,653	487.81	3.33
16.	Uttar Pradesh	14,349	459.07	3.20
17.	Meghalaya	17,288	457.50	2.65
18.	Mizoram	19,054	421.03	2.21
19.	West Bengal	16,805	386.37	2.30
20.	Rajasthan	16,086	364.17	2.26
21.	Arunachal Pradesh	67,321	102.70	0.15
22.	Kerala	17,922	82.01	0.46
23.	Uttarakhand	24,508	42.01	0.17
24.	Sikkim	3358	2.50	0.07
25.	Haryana	1586	1.84	0.12
26.	Himachal Pradesh	14,683	0.91	0.01
27.	Punjab	1772	0.85	0.05
28.	Dadra and Nagar Haveli	213	0.23	0.11
29.	Jammu and Kashmir	22,538	0.11	0.0005

30.	Goa	2219	0.04	0.0
31.	Delhi	180	0.00	0.00
32.	Andaman and Nicobar	6711	0.00	0.00
33.	Chandigarh	17.26	0.00	0.00
34.	Daman and Diu	9.27	0.00	0.00
35.	Lakshadweep	27	0.00	0.00
36.	Puducherry	50.06	0.00	0.00

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299 Table 1. State and Union Territory-wise analysis of percentage of forest burnt area in
300 sq. Km^2 (Reddy et al., 2017).

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Sl no.	**Forest Type**	**Fire Burned area (Sq. Km)**	**Percentage of burned area (in %)**
1.	Tropical wet evergreen forest	651.55	1.14
2.	Tropical semi evergreen forest	1843.31	3.23
3.	Tropical Moist deciduous forest	18717.95	32.77
4.	Tropical dry deciduous forest	26634.40	46.62
5.	Littoral and swamp forest	0.00	0.00
6.	Tropical dry evergreen forest	24.12	0.04
7.	Tropical thorn forest	661.90	1.16
8.	Sub-tropical broad leaved hill forest	147.98	0.26
9.	Sub-tropical pine forest	40.10	0.07
10.	Sub-tropical dry evergreen forest	0.00	0.00
11.	Montane Wet temperate forest	39.65	0.07
12.	Himalayan moist temperate forest	4.49	0.01
13.	Himalayan dry temperate forest	0.00	0.00
14.	Sub alpine Forest	0.00	0.00

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304 Table 2. List of different types of Indian forest area burned in the year 2014 (Reddy
305 et al., 2017)

Effects of a forest fire:

Wildfire is a part of nature. It plays a key role in shaping ecosystems by serving as an agent of renewal and change. But fire can also be deadly and uncontrolled fires affect forest resources in a various ways:

- **Impact on soil properties:** Fire may alter several physical soil properties, such as soil structure, texture, porosity, wettability, infiltration rates, and water holding capacity (Jhariya and Raj, 2014).
- **Soil structure**: Intense burns may have detrimental effects on soil physical properties by consuming soil organic matter. Soil organic matter holds sand, silt, and clay particles into aggregates, therefore a loss of soil organic matter results in a loss of soil structure. By altering soil structure, severe fires can increase soil bulk density, and reduce soil porosity through the loss of macrospores (>0.6 mm diameter).
- **Soil porosity**: Soil porosity can also be reduced by the loss of soil invertebrates that channel in the. When fire exposes mineral soils, the impact of raindrops on bare soil can disperse soil aggregates and clog pores, further reducing soil porosity. Intense fires (> 400°C) may also permanently alter soil texture by aggregating clay particles into stable sand-sized particles making the soil texture coarser and erodible.
- **Erosion**: Intense burns may also induce the formation of a water repellent soil layer by forcing hydrophobic substances in litter downward through the soil profile. These hydrophobic organic compounds coat soil aggregates or minerals creating a discrete layer of water repellent soil parallel to the surface. Water repel-lent soil layers are reportedly formed at temperatures of 176-288^{o}C and destroyed at >288°C. Extensive water repellent layers can block water infiltration and contribute to runoff and erosion.
- **Changes in soil microorganism in fire areas:** Changes and effects of a natural fire on ectomycorrhizal inoculum potential of soil in a *Pinus halepensis* forest. A typically Mediterranean forest of *Pinus halepensis* was studied. During two years following the fruiting fungal species, the number of sclerotia in soil, and the percentages and types of mycorrhizas present were determined. In burned stands, ascomycetes were typical carbonaceous while basidiomycetes were strongly reduced. The sclerotia extracted from soils were mainly Cenococcum. The number of sclerotia in burned stands was greater than in unburned stands. Seven types of mycorrhizas were recognized in *Pinus halepensis* root systems from bioassays:

Cenococcum, E-strain, Rhizopogon, Suillus, Tuber, Xerocomus, and one non-identified. Nearly 100% of the roots were colonized by mycorrhizal fungi. Ectendomycorrhizas represented 50–90% of the total number. The predominant type is ectomycorrhizas formed by ascomycetes included in the E-strain group (Pilar Torres and Mario Honrubia,1997).

- **Major wildfire impacts on people, property, and natural resources:** During the 1990s, several forest fires occurred in the hills of Uttar Pradesh and Himachal Pradesh. From 1995 to 1999, fire hazards in these two states assumed dangerous dimensions. An area of 6,77,700 hectares was affected by these fires. The estimated timber loss from these hazards was the US $ 43 million. Other losses due to these fires included loss of soil fertility, soil erosion, loss of employment, drying up of water resources, and loss of biodiversity these fires brought a major change in the microclimate of the region in the form of soil moisture balance and increased evaporation (Flannigan *et al.,* 2005). The dense smoke from the fires affected visibility up to 14 000 feet (Jhariya and Raj, 2014; FSI, 2017; WWF, 2017
- **Impact of fire on vegetation:** In the present scenario when the conservation of endemic flora and fauna is the priority object certain exotics have become a real menace and threat to the local natives. (Srivastava, 1994, Mathew 1965). *Acacia mearnsii*, *Eupatorium glandulosum,* and *Cytisus scoparius* have become a menace in the Western Ghats and have replaced the valued flora at places. Fire is one of the major factors for such species, which is not only depleting undergrowth but also facilitates the germination of the above-mentioned weeds (Gupta *et al.,* 2014).
- **Forest fire impact on the trees:** Wood properties of *Pinus taeda* L. trees submitted to different burning levels (increasing fire intensity, I–IV). Wood samples were collected from trees in each of the burning levels and also from trees not affected by fire (control). Specimens were then extracted to evaluate the physical and mechanical wood properties; the chemical composition was evaluated only for burning level IV and control. The analysis of the results showed that fire effects over the physical-mechanical properties and chemical composition in all burning levels did not cause sufficient chemical degradation and strength reduction, which could be cause for rejection of those woods for normal use. In the case of structural use caution should be adopted for the wood from burning levels III and IV, which had their mechanical property values reduced (Bortoletto and Moreschi, 2003).

- **Plant adaptations to a forest fire:**

Plants in wildfire-prone ecosystems often survive through adaptations to their local fire regime. Such adaptations include physical protection against heat, increased growth after a fire event, and flammable materials that encourage fire and may eliminate competition. For example, plants of the genus Eucalyptus contain flammable oils that encourage fire and hard sclerophyll leaves to resist heat and drought, ensuring their dominance over less fire-tolerant species. Dense bark, shedding lower branches, and high-water content in external structures may also protect trees from rising temperatures. The use of chemicals in firefighting adds an additional problem to the already dramatic consequences of forest fires. According to a recent study by the Supreme Council for Scientific Research (CSIC), chemicals contained in "flame retardants" used to extinguish fires (such as Fire-Trol) accumulate in the soil for years. Repeated burning leads to devastating loss and irreparable damage to the environment and atmosphere (30% of carbon dioxide (CO_2) in the atmosphere comes from forest fires) [1], in addition to irreparable damage to the ecology (huge amounts of smoke and carbon dioxide (CO_2) in the atmosphere. Among other terrible consequences of forest fires are long-term disastrous effects such as impacts on local weather patterns, global warming, and extinction of rare species of the flora and fauna. Savannah and forest fires annually release 1.7 to 4.1 billion t of carbon dioxide into the atmosphere; additionally, around 39 million t of methane (CH4; 1 t CH4 = 21 t carbon dioxide, CO2) , as well as 20.7 million t of nitrogen oxides (NOx) and 3.5 million tonnes of sulfur dioxide (SO2), are released annually.

Toxic compounds emitted by forest fire:

Wildland fires are major sources of trace gases and aerosol, and these emissions are believed to significantly influence the chemical composition of the atmosphere and the earth's climate system. A wide variety of pollutants released by wildland fire include greenhouse gases carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O)), photochemically reactive compounds (e.g., carbon monoxide (CO),

nonmethane volatile organic carbon (NMVOC), nitrogen oxides (NOx), and fine and coarse particulate matter (PM). Wildland fires influence climate both directly, through the emission of greenhouse gases and aerosols, and indirectly, via secondary

Sl no.	POLLUTANTS	EMISSION FACTOR
1.	Carbon dioxide	1618[a]
2.	Carbon dioxide	1580[b]
3.	Carbon dioxide	1580[c]
4.	Carbon monoxide	113[a]
5.	Carbon monoxide	104[b]
6.	Methane	5.3[a]
7.	Methane	6.8[b]
8.	Non- methane hydrocarbon	8.1[a]
9.	Nitrogen oxides	1.7[a]
10.	Nitrogen oxides	1.6[b]
11.	Ammonium	2.9[a]
12.	Sulphur dioxide	0.57[a]
13.	Sulphur dioxide	0.8[d]
14.	Black carbon	0.66[a]
15.	Organic carbon	6.8[a]
16.	Particulate matter 2.5 µm	61.6[a]
17.	Particulate matter 2.5 µm	13.61[d]
18.	Particulate matter 10 µm	67.0[a]
19.	Nitrogen dioxide	0.2[b]
20.	Organic matter	7.69[d]
21.	Inorganic Fractions	4.67[d]

Table 3. Represents pollutants with their respective emission factors ([a]-Chang, D. et al., 2010; [b] -Saranya, R.K.L. et al., 2016; [c] -Badrinath, K.V.S. et al., 2011; [d]-Reddy, M.S. et al., 2002)

Effects on atmospheric chemistry (e.g., ozone formation) and aerosol and cloud microphysical properties and processes (e.g., the ‘‘Twomey’’ cloud albedo effect; Lohmann & Feichter, 2005; Naik et al., 2007). Wildland fire emissions contribute to air pollution by increasing the atmospheric levels of pollutants that are detrimental to human health and ecosystems and degrade visibility, leading to hazardous or general nuisance conditions. The air quality is also degraded through the emission of primary pollutants (e.g., PM, CO, NOx) and the production of secondary pollutants (e.g., O3, secondary organic aerosol (SOA)) when NMVOC and NOx released by fires undergo photochemical processing. Through direct emissions and secondary chemical and physical processes, wildland fire can have a significant impact on tropospheric chemistry and serve as a major source of air pollution (Shawn et al., 2009).

Forest fires represent an important source of atmospheric trace gases and aerosol particles. Fire influences global ecosystem pattern sand processes, including vegetation distribution and structure, the carbon cycle, and climate. Increased vegetation fire surge releases a high amount of carbon dioxide into the atmosphere. This high amount of CO2 in the atmosphere can be estimated and balanced by alternative conservation plans.

Importance of forest fire study:

Forest fires have been a local issue with global impact, which may happen more frequently than in the recent past due to the impact of rising temperature and global warming.

As Forest fire causes so many changes in our environment and in our lives, it eventually becomes an important factor to study forest fire and how to control it by different management techniques. Mainly the study of forest fire is required to get proper information about the causes of forest fire, fire regimes, impacts, prevention and finally to know how to control forest fire and save nature.

STUDY AREA – THE INDIAN SUBCONTINENT:

The mainland extends between latitudes 8°4'N and 37°6'N and longitudes 68°7'E and 97°25'E (Fig. 2.2). The Tropic of Cancer (23° 30'N) divides the country into almost two equal parts. In the southeast and southwest of the mainland there lies the Andaman and Nicobar Islands and the Lakshadweep islands in Bay of Bengal and the Arabian Sea respectively. India has a geographical area of 32,87,263 km2.

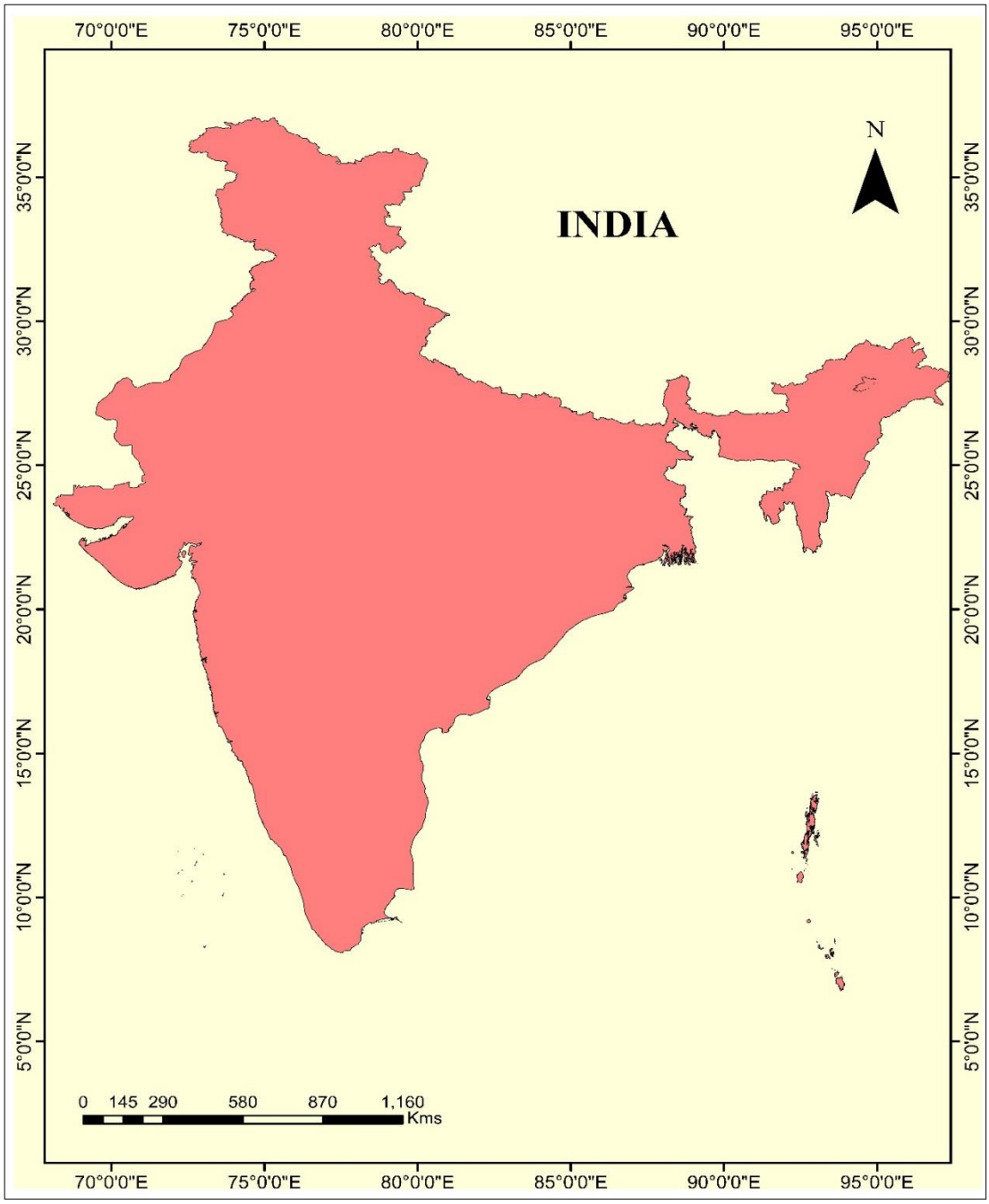

Fig. 3. India map showing longitudinal and latitudinal extent (Bhuvan Portal)

Temperature distribution: Champion and Seth (1968) have recognised 4 types of climatic zones (on the basis of temperature) in India. These are tropical, subtropical, temperate and alpine zone. The mean annual temperature of tropical zone is >24^{0}C and of subtropical zone is 17^0 to 24^{0}C. The mean annual temperature of temperate zone is 7 to 17^{0}C and of alpine zone is under 7^{0}C.

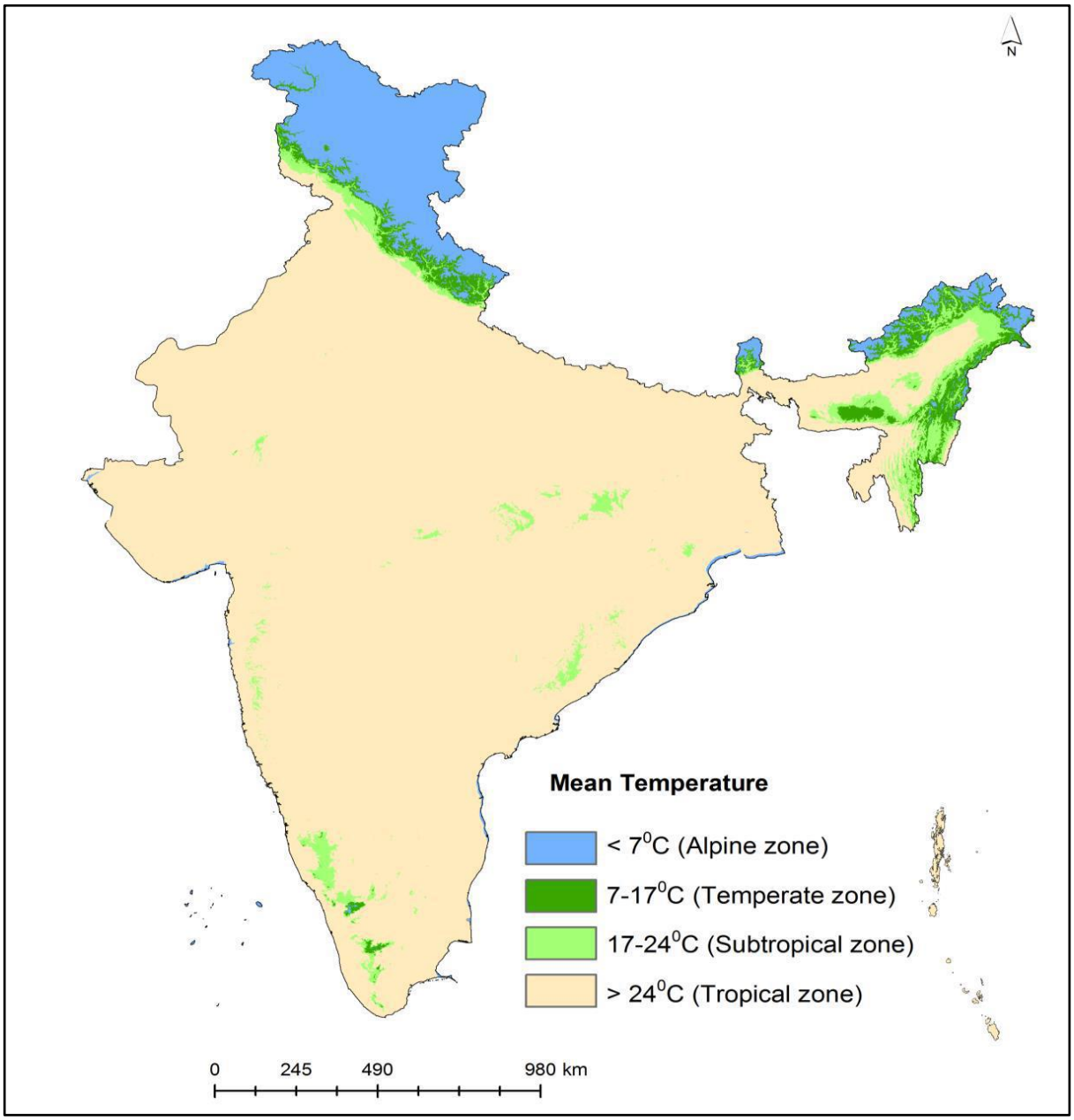

Fig. 4. Annual mean temperature map of India (Reddy et al., 2015)

Precipitation: The mean precipitation zone of India ranges from <50cm to >400cm (Reddy. C. 2015). The mean annual precipitation map of India is given in Fig.4. The Thar desert and Kathiawar region receive less than 50cm rainfall annually while parts of western ghats and north-eastern states of India receive highest rainfall over 400cm annually.

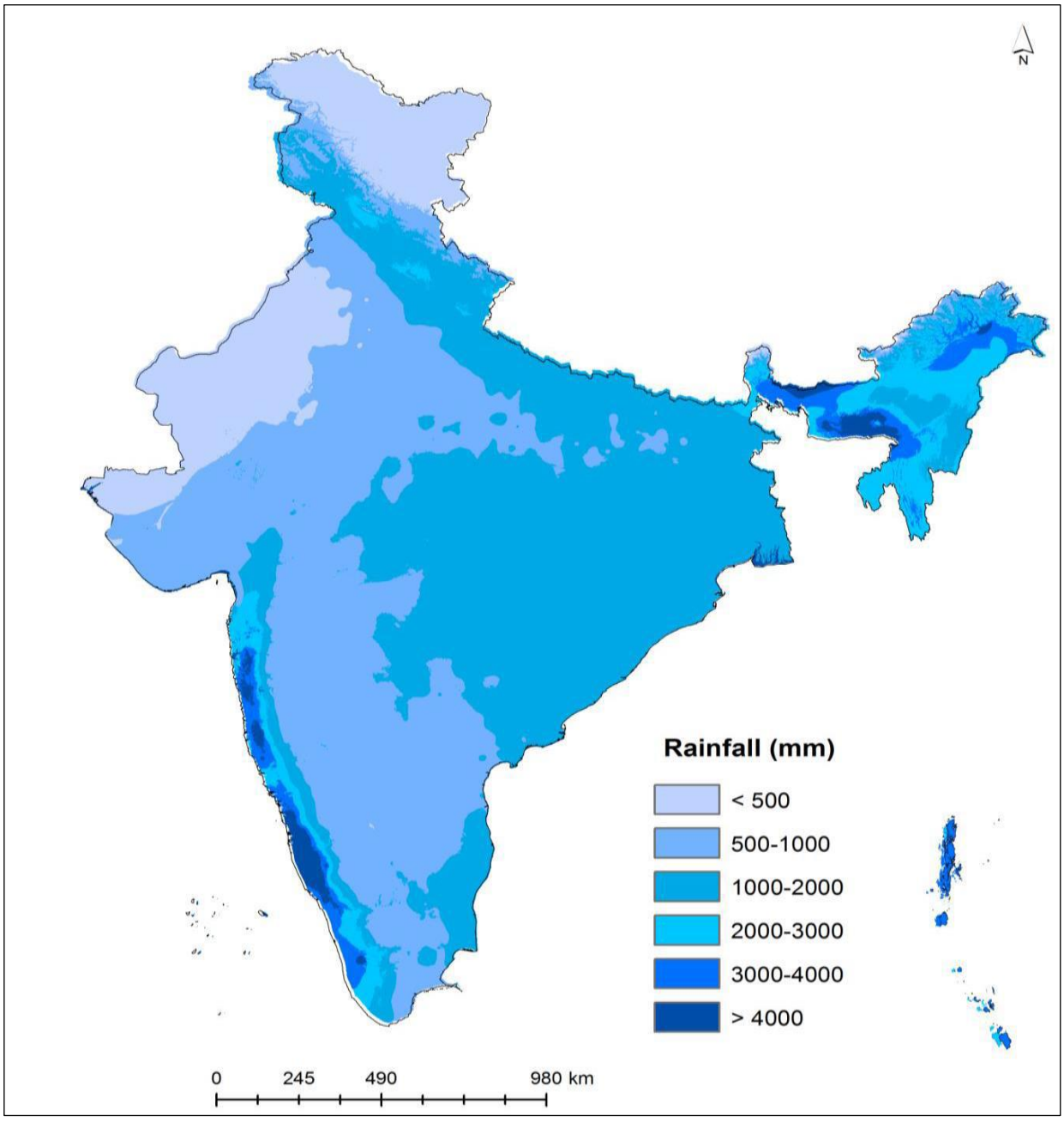

Fig. 5. Annual mean Precipitation map of India (Reddy et al., 2015)

1.1 Types of vegetation (including Forest):

Worldwide there are many definitions of forest that vary from country to country with respect to national laws and environmental stakes. Lund et al 2012 found in a study that there are more than 800 different types of forests in the world. In India forest is defined as all lands more than one hectare in area, with a tree canopy density of > 10 percent irrespective of ownership and legal status. According to FSI forest cover includes all tree species (both native and alien), both naturally grown trees and planted trees, and all types of land irrespective of land use (FSI 2011). Vegetation includes all types of plantations and land cover where the canopy is detected.

The term vegetation refers to all kinds of plants species with their land cover. Vegetation includes forest. Forest can be categorized into the following types, those are Tropical wet evergreen, tropical semi-evergreen, Topical moist deciduous, tropical dry deciduous, Tropical Thorn, Littoral and swamp, Subtropical Broadleaved hill, Subtropical Dry evergreen, Subtropical Pine, Shrubland Himalayan Dry Temperate, Himalayan Moist temperate, Plantation/ orchards, Agriculture, Montane wet Temperate Forests (Reddy et al., 2020). All these types of forests along with some other vegetation types are shown in fig. 5.

Tropical wet evergreen forest: is a type of forest with high heat and high humidity, the trees of these forests do not shed their leaves together. Trees here reach the height of *45 – 60 meters* in height. The important species of these forests are mahogany, mesua, white cedar, jamun, canes, bamboo, and many more. The bark of the trees is thin and smooth. The trees in this forest form a multi-layered pattern: shrubs cover the layer closer to the ground (understory), followed by the short trees (middle story) and then the tall trees (top story). Ferns and different species of orchids grow on the trunks of the trees. Mosses and aroids are quite common. Wet evergreen forests are mainly found in the high rainfall areas of the Western Ghats, Andaman, and Nicobar Islands, Eastern Himalayas and the north-eastern region (Reddy et al., 2015).

Subtropical broad leaved hill forest this forest is found in the Himalayan, North East, Aravalli, the Western Ghats ranges, and in the states of Darjeeling, Uttar Pradesh, and Bihar. Flora of this forest is a mixture of wet evergreen forest and temperate forest. Common species of Orchids, bamboos, and creepers are found in this forest (Roy et al.,2015)..

Tropical semi-evergreen forest: this forest is found in the Western Ghat, Eastern Himalayas, Andaman and Nicobar Island, and Odisha. Trees found in this forest are a mixture of wet evergreen and moist deciduous trees, more than 75 % of trees remain green throughout the year. The annual rainfall required for this forest is 200-250 cm (Roy et al., 2015).

- **Tropical moist deciduous forest:** In these forests mostly seasonal trees and few evergreen trees are present. Here drylands are found in patches. The trees are grown under such a condition where they get an nnual rainfall of 100 cm – 200 cm and also experience a dry climate for half of a year, they shade their leaves in the dry season in order to avoid water loss. It is found in North-eastern states, the Western Ghats, Himalayan foothills, and in some states like Jharkhand, West Bengal, Western Odisha, Chhattisgarh and Andaman, and Nicobar Island (Roy et al., 2015).
- **Tropical dry deciduous forest:** Trees of this forest also grows under half rainy and half-dry season but they receive annual rainfall between 100-70cm and it is less humid than moist deciduous forest. During dry season the trees shade their leaves and look like a huge grassland. The bark of the tree found here are thick and rough. This forest is found in Dry part of India like the Southern region of the Deccan plateau, Odisha, Chhattisgarh, Bihar, Telangana, Andhra Pradesh and Uttar Pradesh (Roy et al., 2015).
- **Tropical thorn forest:** This forest has shrub-like vegetation, that do not grow above 10 m and they have Thorns and spines-like modifications. Climbers and sun-loving weedy species are commonly found in this forest. Water availability for the plants is low as the annual rainfall is less than 50 cm and to absorb water plant roots goes deep down the soil. This type of forest is found in Thar desert, Gangetic plains, Deccan, and Semi-arid regions and in some states like South-west Punjab, Gujrat, Rajasthan, Haryana, Madhya Pradesh and Uttar Pradesh (Roy et al., 2015).
- **Sub-tropical pine forest:** This forest consists of conifers, more specifically Pinus roxburghii . This pine forest is prone to fire which is why small grasses are found on the ground. It is found in the north-east, Eastern Himalayas and Western Himalaya and in states of Jammu & Kashmir, Himachal Pradesh, Sikkim and Uttarakhand (Roy et al., 2015).
- **Himalayan moist temperate forest:** This forest is also rich in conifers and they also contain shrubs and grasses on the ground. The annual rainfall varies from 150

cm to 250 cm. It is found throughout the Himalayan region, Sikkim, Kashmir, Darjeeling, Uttarakhand, and Himachal Pradesh (Roy et al., 2015).

- **Subalpine forest:** This forest contains both conifers and broad leave trees, epiphytic mosses, lichen, and ferns are also predominantly found. Forest area ranges from the Himalayas to the North-eastern region, which are Kashmir, Arunachal Pradesh, and Sikkim states of India (Roy et al., 2015).
- **Shrubland**, scrubland, and scrub, brush, bush or scrub forest is a biome that consists a high number of dense shrubs or bushes species including grasses and herbs. In such areas, precipitation is very low with continuous and high wind speed andpoor-averagee soil quality.

A few types of the forests taken into account in this study are:

- **Tropical Moist scrub:** Here broad-leaved evergreen shrub foliage are the dominant shrub species and tree canopy cover is <10% (Reddy et al., 2015).
- **Tropical Dry scrub:** Here broad-leaved deciduous shrub foliage are the dominant shrub species and tree canopy cover is <10% (Reddy et al. 2015).
- **Subtropical scrub:** Here the dominant shrub foliage is evergreen needle-leaved or broad-leaved or deciduous broad-leaved and tree canopy cover is <10% (Reddy et al., 2015).
- **Temperate scrub:** here the dominant shrub foliage is evergreen needle-leaved or broad-leaved and tree canopy cover is <10% (Reddy et al., 2015).
- **Moist Alpine scrub:** It is a low evergreen scrubland, where the dominant species is Rhododendron. The ground is covered by mosses, ferns, alpine shrubs, and thick layer of black humus in some regions. This area experiences heavy snowfall. This scrubland ranges from hills of the Himalayas to the Myanmar border and in some of the Indian states like Sikkim, Arunachal Pradesh and Himachal Pradesh (Reddy et al., 2015).
- **Dry Alpine scrub:** It is the uppermost limit of xerophytic scrub, dominated by dwarf shrubs such as Juniperus communis, J. recurve. Plants of this area experience precipitation under 800mm and high snowfall. This scrubland is found at an elevation of 3000 m – 5200 m (Reddy et al., 2015).
- **Mangrove scrub:** These are the shrubs that grow in the coastal area, saline or brackish water. Mangroves are generally salt-tolerant and can secret excess salt from their leaves, in some cases they can absorb fresh water from the saline water. The root

of these plants emerges out of the soil for gaseous exchange. They experience high precipitation as they are in the coastal region.

- This scrub is found in the coastline of Bay of Bengal, the Krishna-Godavari delta Indian ocean, and in states like Odisha, West Bengal, Tamil Nadu, Andhra Pradesh and Andaman & Nicobar Island.
- **Littoral and swamp forests:** Littoral and swamp forests or Mangroves are found in the coastal belt of India. These are halophytic evergreen and have pneumatophores/stilt roots and viviparous germination i.e., the seeds germinate while still on the 'mother' trees. Species are relatively few, but occur gregariously. Generally, fruits/seeds of the species are large but lighter than water (Reddy et al., 2015).
- **Savanna:** Lands dominated by naturally occurring grasses and forbs with scattered trees or shrubs. The vegetation height exceeds 1 meter (Reddy et al., 2015).
- **Barren land:** Barren lands generally result from inherent/imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints. These are the areas with exposed soil, sand, rocks and never more than 10% vegetation cover during any season. Rann of Kachchh of Gujarat represents unique combination of saline desert and highly dynamic seasonal wetlands also included under barren lands. In addition, long fallow lands are included in this category (Reddy et al., 2015).
- **Water bodies:** This category comprises areas with surface water, either impounded in the form of ponds, lakes, tanks and reservoirs or flowing as streams, rivers and canals (Reddy et al., 2015).
- **Snow:** Lands with a snow cover. It includes perennial snowfields and glaciers of the Himalayas (Reddy et al., 2015).
- **Settlements:** It is an area of human habitation. Included in this category are cities, towns, villages, major transportation facilities and areas occupied by industries (Reddy et al., 2015).
- **Plantations/Orchards:** Plantations are areas occupied for the purpose of afforestation or reforestation or commercial purposes. Teak, sal, pine, rubber, Eucalyptus, and Casuarina are the major species (Reddy et al. 2015). Orchard is mainly a plantation of fruit or nut-bearing trees like mango, coconut, orange, apple or cashew, and other horticultural plants. Orchards are mostly found in Maharashtra,

Punjab, Himachal Pradesh, Uttar Pradesh, Bihar, Meghalaya and Manipur states of India.

- **Agriculture land:** These are the vegetation type where cultivation of some cereal, vegetables, textile and many more crops are done to feed a nation. Generally, the plants here are small in height and they require adequate rainfall for proper growth and high yield. India is one of the largest producers of agricultural products. Almost all states of India have agriculture land cover but the top ten states are West Bengal, Uttar Pradesh, Punjab, Gujrat, Haryana, Madhya Pradesh, Assam, Andhra Pradesh, Karnataka and Chhattisgarh.
- **Montane wet temperate forest:** It is a closed evergreen forest. These forests occur in the higher hills of Eastern Himalayas, North East and Western Ghats (Nilgiris, Palnis, Anamalais and Tirunelveli hills) and are found about 1500 m upwards. Such forests are found in patches in the more sheltered sites on rolling grasslands in the Western Ghats, popularly known as 'shola'. The conifers are absent. Trees have large girth and branching crowns. The height of trees reaches mostly up to 15 m only. Leaves are coriaceous and red during the tender stage. The branches are densely clothed with mosses, f,erns and epiphytes. Woody climbers are also common. FCC image shows these areas in a dark brown tone with medium the o rough texture (Reddy et al., 2015).

Among all the vegetation types this study only involves fire effects, detection, and management in forest in the Indian context.

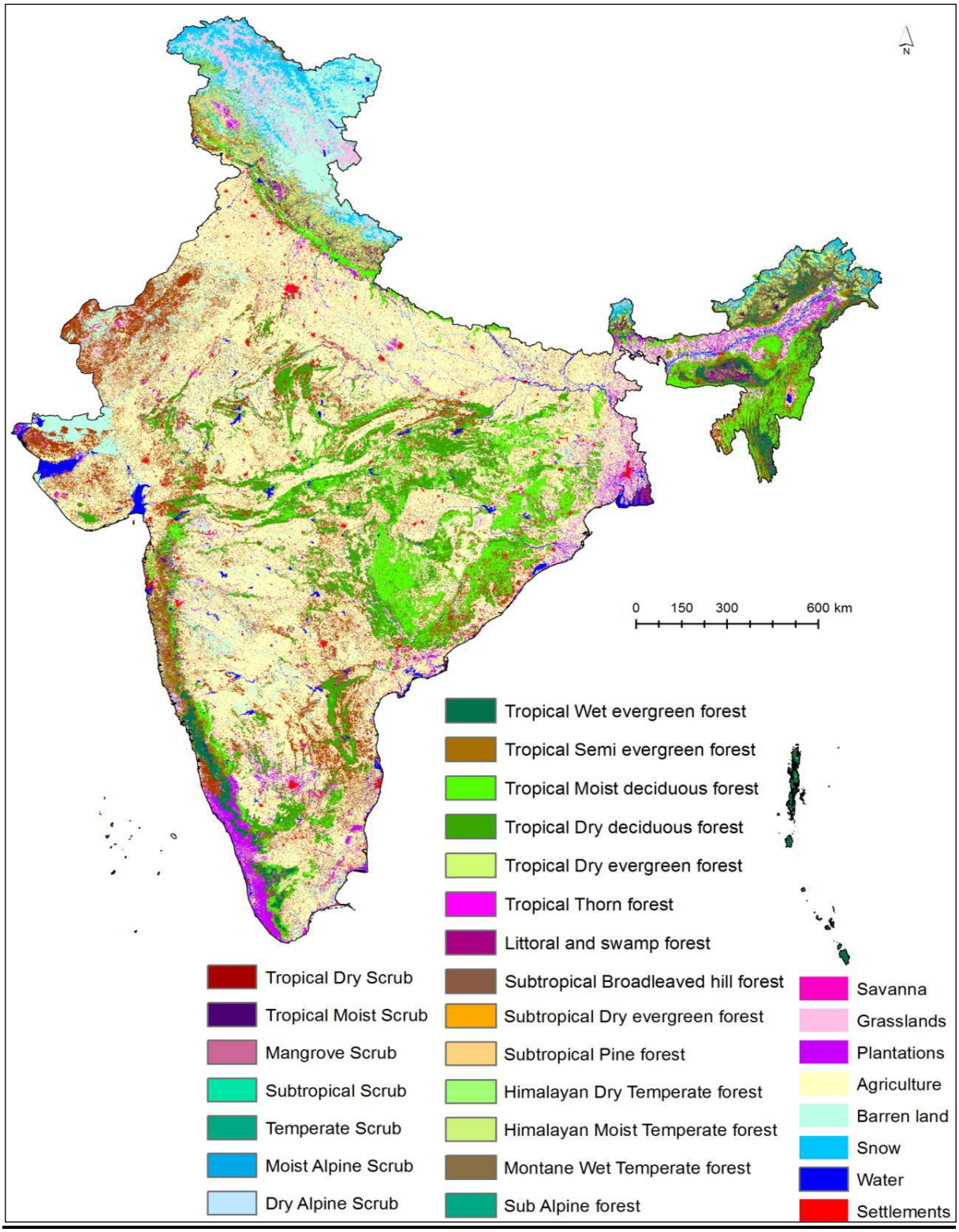

Fig. 6. Vegetation type and land cover map considering Indian Subcontinent is shown here (Reddy et al., 2018).

Fire location: India includes a total natural vegetation cover (vegetation here is considered as, forest, scrub, grassland, savanna, agricultural land and plantations) of 9, 65,128 km^2, which is 29.36% of the total geographical area of India (Reddy et al., 2015). Fire in the vegetation cover can be measured through satellite sensors and can also be located in maps. MODIS image showing fire locations in forest biomass burning in fig.6.

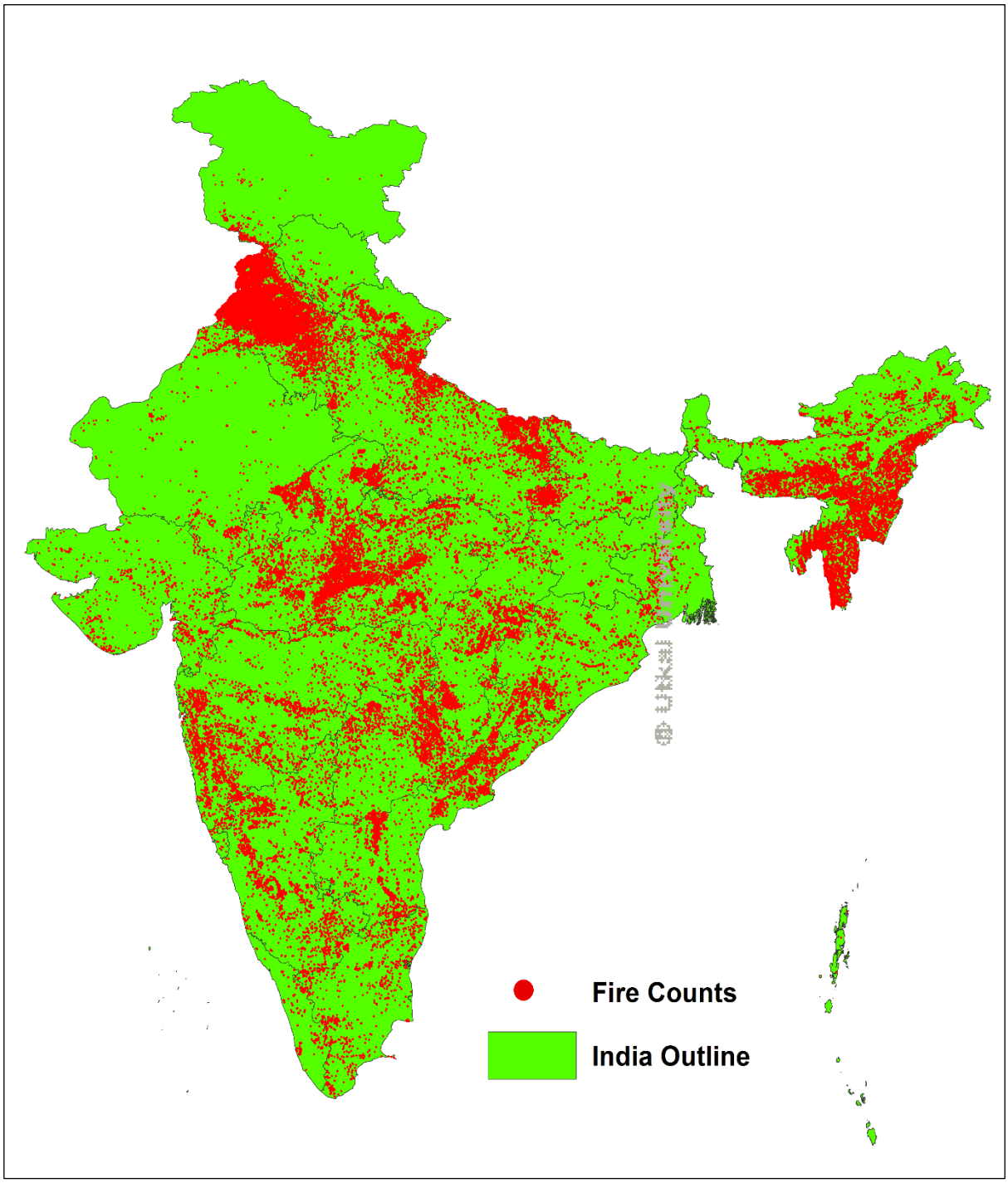

Fig. 7. MODIS image of Indian map with fire count (NASA FIRMS 2019-2020)

REVIEW OF LITERATURE:

- **Reddy, M.S. et al., (2002):** This study is based on A spatially resolved biomass burning data set, and related emissions of sulfur dioxide and aerosol chemical constituents for India, in 1996–1997 and extrapolated to the INDOEX period (1998–1999). Here sources include biofuels (wood, crop waste, and dung-cake) and forest fires (accidental, shifting cultivation, and controlled burning). Particulate matter (PM) emission factors were compiled from studies of Indian cooking stoves and from literature on open burning. Black carbon (BC) and organic matter (OM) emissions were estimated from these, accounting for combustion temperatures in cooking stoves. Sulphur dioxide emission factors were based on fuel sulphur content and reported literature measurements. Biofuels accounted 93% of total biomass consumption ($577 MT yr^{-1}$), with forest fires contributing only 7%. The national average biofuel mix was 56: 21 :23% of fuelwood, crop waste and dung-cake, respectively.

  This study concludes that compared to fossil fuels, biomass combustion was a minor source of SO2 (7% of total), with higher emissions from dung-cake because of its higher sulphur content. PM2.5 emissions of 2.04 Tg yr^{-1} with an ‘‘inorganic fraction’’ of 0.86 Tg yr^{-1} was estimated. Biomass combustion was the major source of carbonaceous aerosols, accounting 0.25 Tg yr^{-1} of BC (72% of total) and 0.94 Tg yr^{-1} of OM (76% of total). Among biomass, fuelwood and crop waste were primary contributors to BC emissions, while dung-cake and forest fires were primary contributors to OM emissions. Northern and east-coast India had high densities of biomass consumption and related emissions. Measurements of emission factors of SO2, size-resolved aerosols, and their chemical constituents for Indian cooking stoves are needed to refine the present estimates.

- **Reddy, M.S. et al., (2002):** The present study is based on spatially resolved seasonal carbonaceous aerosol emission inventory for India from open crop waste burning and forest fires on a global basis major source of carbonaceous aerosols is biomass burning [*Liousse et al.*, 1996]. The long-term aerosol optical depth (AOD) measurements at Kaashidoo Climate Observatory (KCO) in the remote Indian Ocean show large inter-annual. Carbonaceous aerosols account for 23-27% of measured total aerosol mass concentration and contribute to 20-40% of AOD [*Ramanathan et al.*, 2001].

673 This study suggests that there is strong seasonality in burning of the waste, with
674 February-May period accounting 48% of the total black carbon, organic carbon and
675 PM 2.5 emission is 80, 164, and 492 Gg yr-1 respectively. The prominence of open
676 burning emissions during dry season that is between March – May (at this time
677 forest fire is at its peak) of the year would result in long-range transport of the
678 aerosols. The high forest fire emissions during INDOEX-IFP 1999 could be one of
679 the reasons for the measured very high AOD (aerosol optical depth) at KCO
680 (Kaashidoo Climate Observatory) in 1999.

681 • **Venkatraman, C. et al., (2006):** Have worked on, high-resolution satellite data of
682 active fires and land cover classification from MODIS is done. Both on a scale of 1 km × 1
683 km, were used to capture the seasonal variability of forest and crop waste burning and in
684 conjunction with field reporting. Here open biomass burning representative of 1995–2000
685 from forests using burned area and biomass density specific for Indian ecosystem is
686 estimated. The fire season in forest areas was from February to May, and that in
687 croplands varied with geographical location, with peaks in April and October
688 corresponding to the two major harvest seasons.

689 Forest and shrubland biomass burned in India was estimated as 32 Tg yr_1, with the
690 largest burning in central India followed by the east-northeast. The peak in forest
691 biomass burning occurs in February–May. Open biomass burning contributes
692 importantly (about 25%) to Black carbon, Organic carbon and Carbon monoxide
693 emissions, a smaller amount (9–13%) to PM2.5 and Carbon dioxide emissions, and
694 negligibly to Sulphur dioxide emissions (1%). black carbon,

695 organic matter, Carbon monoxide, PM2.5, Carbon dioxide and Sulphur dioxide.

696 • **Badarinath, K.V.S. et al., (2006)**: Have studied Simultaneous observations of
697 black carbon aerosol mass concentration, carbon monoxide and ozone were analysed
698 at an urban station of Hyderabad, India, during March to May 2006 coinciding with
699 the forest fire season over the region. High values of black carbon (BC) aerosol and
700 carbon monoxide were observed during last week of March and certain days of April
701 and May, 2006 with wind trajectories coming from the north of the study area.
702 DMSP-OLS night time satellite observation of forest. Fires over the region showed
703 active forest fires during the days with high values of BC, CO and O3. Black carbon,
704 Carbon monoxide, ozone. The fire counts derived from satellite matched the
705 incidence of higher values of BC, CO and ozone. The scatter plot between CO and
706 BC showed a positive correlation with forest fire occurrences over the region

suggesting that they are originating from the same source. BC showed a negative correlation with ozone concentration and is attributed to the fact that a higher concentration of BC provides more surface area for catalytic reaction for destruction of tropospheric ozone.

- **Chang, D. et al., (2010):** They estimated the L3JRC burned-area product and the Collection 5 MODIS (MCD45A1) burned-area product were used to define the area burned in tropical Asia for seven fire years 2000 – 2007. Available fuel loads and emission factors were assigned to each vegetation type in a GlobCover characterization map, and fuel moisture content was taken into account when calculating combustion factors. The size of the L3JRC burned areas ranged from 36031 km^2 in the fire year 2005 to 52 303 km^2 in 2001, and the MCD45A1 burned areas ranged from 54 790 km^2 in the fire year 2001 to 148 967 km^2 in 2004. Fire emissions were mainly concentrated in Indonesia, India, Myanmar, and Cambodia. National statistics estimated that approximately 14 500–37 300 km^2 of Indian forest were affected by fires annually and India is one of the major contributors emissions. Among tropical Asian countries India is second in CO emission. Comparisons of L3JRC and MCD45A1 burned areas using ground-based measurements and other satellite data were made in several major burning regions, and the results suggest that MCD45A1 generally performed better than L3JRC, although with a certain degree of underestimation in forest areas. Forest burning was identified as the major source of the fire emissions due to its high carbon density. Although agricultural burning was the second highest contributor, it is possible that some crop residue combustion was missed by satellite observations. In addition, the majority of fire emissions were attributed to forest fires, followed by cropland, shrubland, and grassland fires. In this study the following pollutants are emitted Carbon dioxide, Carbon monoxide, Methane, Non-Methane hydrocarbons, Nitrogen oxides, Ammonia, Sulphur oxide, Black carbon, Organic carbon, PM2.5, and PM10.
- **Badarinath, K.V.S. et al., (2011):** In the present study burnt area estimates derived from the L3JRC products are used to estimate the CO2 emissions from forests. The results suggested that an average of 2,414 sq. kms. is burnt annually. On an annual basis, the total area burnt for all of India derived from L3JRC was about 30,603 sq. kms., of which forest biomass burning constituted 2,414 sq. kms., nearly 7.8% of the total area. Of the different years, 2000-2001 recorded the greatest area burnt

followed by 2003-2004, with the least during 2002-2003. Spatial patterns in the burnt area maps clearly revealed the greatest burnt areas were located in the Himalayan region. A variety of forest types exist in India, from the tropical evergreen forests of Kerala and Assam to the conifers of the Himalayan region, and from the tropical deciduous forests of Madhya Pradesh and Orissa to the thorny scrub forests of Rajasthan. The burnt area estimates derived from the forested areas may have fewer errors, but validation is required to account for uncertainties. In addition to area estimates, fuel type, fuel load and combustion efficiency can also affect emissions calculations. In our case, we have used the MERIS 300m Globcover map for delineating forested areas. Over a period of seven years, closed needleleaf evergreen forest recorded the largest burnt areas (1087 sq. kms.) of the different forest types, followed by closed broadleaf deciduous forests (937 sq. kms.) and others. They have estimated annual CO2 emission of nearly 6.34 CO2 Tg/yr from biomass burning of forests, hence there is a need to address this issue through effective fire policies and management.

- **Saranya, K.R.L. et al., (2014):** The present work has been carried out to locate and estimate the spatial extent of forest burnt areas using Resourcesat-1 data and fire frequency covering decadal fire events (2004–2013) in Similipal Biosphere Reserve. The anomalous quantity of forest burnt area was recorded during 2009 as 1,014.7 km2. The spatial analysis of burnt area shows that an area of 34.2% of dry deciduous forests, followed by tree savannah, shrub savannah, and grasslands affected by fires in 2013. Geospatial analysis indicates, an area of 2,175.9 km^2 (59.6 % of total vegetation cover) affected by fires during 2004–2013. It is evident from analysis that, during last 10 years of study an area of 12.2 km^2 has experienced regular annual fires. The areas affected by fires more than 5 years have been estimated as 18.9 % of burnt areas. The annual burnt area proportionately is in the minimum range of 11.5 % in 2005 to maximum of 27.8 % in 2009 of total vegetation area. Average estimate based on decadal data reveals that every year an area of 738 km^2 (20.2 %) is experiencing forest fire.
- **Saranya, K.R.L. et al., (2016):** In the present study, in the present study, the spatiotemporal patterns of forest fires were examined from 2004 to 2013 in Similipal Biosphere Reserve, Eastern Ghats of India. The total area affected under forest fire has been estimated as 23.7% in 2004, 11.5% in 2005, 24.8% in 2006, 23.5% in 2007

and 18% in 2008, 27.9% in 2009, 16.4% in 2010, 16.3% km2 in 2011, 27% km2 in 2012 and 14% in 2013. CO2 emissions were estimated for tropical vegetation types that is semi-evergreen, moist deciduous, dry deciduous, high-level Sal, low-level Sal Forest, scrub, savannah and grasslands.

This study mainly focuses on the total carbon emissions from forest fire in Similipal biosphere reserve (SBR) vary from 0.93 to 1.58 CO_2 Tg yr^{-1} over a decade. The mean annual rate of carbon emissions was observed to be 1.26 CO_2 Tg yr^{-1} for a decade. So, total about 12.68 CO2 Tg yr-1 has been released for a decade. Zone wise analysis of emissions is done in this study that indicates buffer and core zones of SBR emitting more carbonaceous gases rather than transition zone. Similarly other trace elements like Methane, Nitrous oxide, Nitrogen oxides, Carbon monoxide has also been calculated. This study is helpful in formulating conservation plans and thus helps in mitigating the impact of climate change.

- **Reddy, S.C. et al., (2017)**: In this study India wide forest burnt area is quantified and analysed using AWiFS data for the year 2014. The total burnt area under vegetation cover (forest, scrub and grasslands) of India was estimated as 57,127.75 sq. km. In 2014, 7% of forest cover of India was affected by fire. Among major forest types dry deciduous forest is most affected by forest fire followed by moist deciduous forest.

  According to this study highest burnt area in the year 2014 is recorded in the state Odisha that is 8186.46 sq.km. that is 16.26% of total forest area of Odisha, followed by Andhra Pradesh, Maharashtra, Chhattisgarh, Tamil Nadu, Madhya Pradesh, Telangana, Jharkhand, Manipur and Karnataka. The database generated would be useful in ecological damage assessment, fire risk modelling, carbon emissions accounting and biodiversity conservation.
- **Yarragunta, Y. et al., (2020):** In present study the impacts of gaseous pollutants were estimated by using Weather Research and Forecasting model coupled with chemistry (WRF-Chem) and in-situ observations of these gases over Dehradun. During Event 1, they observed CO mixing ratio over Dehradun increased from 25th April onwards, attained maximum (705.8 ± 258 ppbv) on 2 May 2016 and subsequently decreased. During Event- 2, daily average concentrations of CO, O3, and NOx showed systematic increase over Dehradun during HFAP period. The rate

of increase of CO was 9 ppbv/day, while it was very small for NOx and O3. To quantitatively estimate the influence of forest fire emissions, two WRF Chem simulations were made: one with biomass burning (BB) emissions and other without BB emissions. For 2016 fire event, WRF-Chem simulation showed 52% enhancement in CO, 52% enhancement in NOx and 11% enhancement in O3 during HFAP. A clear positive corelation (r = 0.89) were observed between $\Delta O3$ and ΔCO indicating rapid production of ozone in fire plumes. For 2018 fire event, During HFAP, WRF-Chem simulated CO and NOx levels enhanced significantly by 34% and 32%, respectively while O3 levels enhanced by 9%.

The burnt area was estimated as 3774.14 km2 (15.3% of total forested area of Uttarakhand) for Event-1 and 690.8 km2 (2.8% of total forested area of event-2. In event 1 increase pollutants like CO and O3 level is seen in atmosphere of south and south-eastern parts of Uttarakhand. In event-2 CO, O3 and NOx level is increased in southern parts of Uttarakhand.

- **Reddy, C. S. et al (2020)**: Present study attempted to analyse fire occurrences to determine the distribution of vegetation fire hotspots in Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka, and Myanmar. The spatial statistics and space–time pattern mining tools are used for investigating fire trends that occurred across vegetated landscapes over a period of 16 years. This study found a total of 2,352,063 active vegetation fire locations using daily MODIS data from 2003 to 2018. Mann–Kendall test has identified the statistically significant trend of fire hotspots across forests, scrub, grasslands, agriculture, and plantations. The emerging hotspot analysis detected considerable spatial variation across fire hotspots and identified the geographical clusters of fire hotspots across the South Asian countries and Myanmar. Most of the fires in wet evergreen forests are due to slash and burn practices in Myanmar and north-east India, which is a major threat to the endemic and threatened species. The crop residue burning is responsible for persistent and intensifying hotspots in north-western India. This information of prioritized geographic clusters of fire hotspots provides an insight into the potential future trajectories, predicting risk areas, ecological damage assessment, and conservation planning.

FOREST FIRE MANAGEMENT:

: Prevention of forest fire

Some of the important SLFM actions for the prevention and control of forest fires were identified as follows:

- Identification of fire-prone areas and its mapping.
- Compilation of data on forest fire damage.
- Development and installation of danger rating tools for forest.
- Development and deployment of forest fire forecasting systems.
- Activities related to forest protection to be made part of planned activity to ensure allocation of budget.
- Preventing measures to be ensured well before the fire season (i.e., summer).
- Designation and appointment of nodal officer to coordinate with various agencies on forest fire–related issues.
- A "fire control committee" to be constituted at each of the levels, namely, block, district, and state headquarters, for the monitoring as well as control of the fire. They should be entrusted with sufficient resources to fight fire incidences.
- Communication network should be in place for ensuring timely flow of information, manpower, and materials to fire sites.
- JFM (Joint Forest Management) or similar committees should be trained and engaged for the forest fire control and management. Specially, people living near to the forests must be an integral part of such committees.
- Regular training of forest staffs and other fire protection committee members should be organized to update the participants on new information and tools to safeguard forests from fire.
- Public awareness should be done to protect forests from fires.
- Stringent legal actions to be ensured for the prevention of forest fires.
- **Firewatch** (Automatic early warning system for forest fires) It is a terrestrial, digital, remote surveillance system which is capable of observing larger wooded regions, and to analyse, evaluate, link and store the collective data. Due to its sensitivity, accuracy and reliability the system enables an early recognition of forest fires.
- **Fire detection using radio-acoustic sounding system** Sahin and Ince (2009) proposed system for early detection of crown and surface but not ground fires using

radio-acoustic sounding system (Figure 2). In addition, that system can be combined with existing systems to augment the efficiency of fire detection for all types of wildfires.

- **Educational measures** to increase awareness of the danger and damage due to forest fire have also been demonstrated by the project. Posters bearing a fire prevention message or fire risk meters have been installed through the divisions in the project areas, to increase public awareness of seasonal fire severity.

Software monitoring

The emission of energy in the form of light and heat during the burning process can be easily detectable in electromagnetic (EMR) spectrum. The changes in the reflectance spectrum before (standing vegetation) and after combustion (ash and char) can be measured using sensors on remote platforms. Earth-observing satellite sensors have been used since the 1970s to detect these changes, to quantify the burnt areas and to determine the composition and distribution of by-products after fire.

- Operational fire monitoring using remote sensing data has become a standard activity of many governments and international agencies in response to concerns over the loss of forests and effects of widespread burning on global atmosphere. MODIS Rapid Response System Global Fire Maps, GLOBSCAR, European Forest Fire Information System, WEB FIRE MAPPER, GOFC/GOLD Fire Monitoring and Mapping Implementation Team, Canadian Wildland Fire Information System and Indian Forest Fire Response and Assessment System (INFFRAS) are some of the examples of global, regional and national initiatives for assessing the fire dynamics.
- Also, other information systems such as International Geosphere–Biosphere Program (IGBP) and NASA's Landsat Pathfinder Project on Deforestation in the Humid Tropics, are important for mapping the surrogate variable of fire flux.

Control of forest fire:

- **Fire lines:** Creation of patches across an area where there are chances of fire spread is there. It has to be cleared afresh every year. As the continuity may be created by the grown vegetation. It can be roads also or vice versa.
- **Aerial firefighting:** Aerial firefighting is the use of aircraft and other aerial resources to combat forest fires. The types of aircraft used include fixed-wing aircraft and helicopters. Smoke-jumpers and rappelers are also classified as aerial firefighters, delivered to the fire by parachute from a variety of fixed-wing aircraft, or rappelling from helicopters. Chemicals used to fight fires may include water, water enhancers such as foams and gels, and specially formulated fire retardants.
- **Air tankers:** Airtankers or water bombers are fixed-wing aircraft fitted with tanks that can be filled on the ground at an air tanker base or, in the case of flying boats and amphibious aircraft, by skimming water from lakes, reservoirs, or large rivers. Air tankers are large planes equipped with tanks for transporting and dropping fire retardant (e.g., diammonium phosphate) or water in order to slow a fire down in support of fire line construction operations on the ground. Air tankers are primarily used for initial attack and structure protection. Typically, a red dye is added to chemical retardants to provide pilots with visual markers of drop accuracy. Capacities range from 2,000 to 3,000 gallons, although feasibility tests have been conducted for larger capacities (e.g., a 747 jumbo jet). Single engine air tankers have less capacity but greater mobility, an added advantage in mountainous areas.
- **Fire retardant:** Borate salts were used in the past to fight wildfires but were found to sterilize the soil, were toxic to animals, and are now prohibited. Newer retardants use Ammonium sulphate or ammonium polyphosphate with attapulgite clay thickener or Diammonium phosphate with a guar gum derivative thickener. These are not only less toxic but act as fertilizers to help the regrowth of plants after the fire. Fire retardants often contain wetting agents, preservatives and rust inhibitors and are coloured red with ferric oxide or fugitive colour to mark where they have been dropped. Brand names of fire retardants for aerial application include Fire-Trol and Phos-Chek
- **Chemical fire control:** Retardants and foams make water more efficient as a suppressant by spreading water out over a surface and penetrating more deeply into porous fuels, much like a detergent extends water's usefulness for cleaning

purposes. Some retardants also lower ignition temperatures, thus quickening fuel conversion while discouraging flaming and hastening extinction. Fire engines on the ground control operation make use of water and water enhancers such as fire retardants and foams. The retardant (slurry) dropped by airtankers and helicopters consists of water (85%), diammonium phosphate or sulphates (10%), and minor ingredients (5%). The mixture weighs about 9 lb per gallon, or approximately 1 kg per litre. Diammonium phosphate is the active ingredient that inhibits combustion and fertilizes the soil after the fire is out. Minor ingredients include iron oxide (a red dye, allowing the pilot to check the accuracy of the drop by providing visual evidence of spray pattern), and gums and clay thickeners. Use of aerial retardants may be restricted near creeks and streams due to possible toxicity effects on water fauna.

CONCLUSION:

This study is all about a review on forest fire considering the Indian Subcontinent, where it is shown that how approximately every year due to forest fire our environment suffers from a great loss of flora and fauna, which also pollutes our surroundings by releasing harmful gases into the atmosphere, as shown in table 3., due to which human many other animals' health is deteriorating day by day. According to a Forest Survey of India Report, about 50 percent of forest areas in the country are fire-prone (ranging from 50 percent in some states to 90 percent in the others) and about 6 percent of the forests are prone to severe fire damage. Nowadays the major reason behind forest fire is anthropogenic which is either due to human irresponsibility or their deliberate actions. Here forest fire mostly occurs between February- and May due to the dry season. In India among all the different types of forests discussed above "Tropical deciduous forests" are the most fire-prone forest (Reddy et al., 2020; Reddy et al., 2017; GFMC 2002) and hence are more damaged due to forest fire as shown in table 2. Other vegetation like agricultural fields is also vulnerable to fire and forest near those agricultural land is thus fire-prone.

Forest Fire is not large-scale destruction but it can cause slow and consistent degradation of nature someday, which might lead to loss of species, break-in gene pool, break of a food chain that will ultimately result in loss of a healthy ecosystem. To avoid this, we should try to conserve our environment by saving forest which is the source of our living. Protection of forests from fire is easy nowadays, especially with the use of remote sensing techniques but still, we need to pay more attention and create more awareness among people to prevent fire occurrence. We can also record data of forest fires occurring every here and now so that we can estimate the loss that took place due to forest fire and can plan a strategy of recovery. Along with forest loss, this record can also be used to determine the hotspot location, create fire alerts, and for future research work.

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