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REVIEWING THE IMPACT OF FOREST FIRES ON ENVIRONMENTAL CONDITIONS: A COMPREHENSIVE ANALYSIS

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ABSTRACT

Currently, a forest fire is a core issue of forest deterioration and ecosystem services across the globe. The world forest faces extreme fire that degrades a large area of the forest result loss in the ecosystem and biodiversity. Most of the fire incidences occur because of the increasing activities of the human in a forest area. Intentionally, forest residents and tribal communities set fire for collecting forest produces and cultivating agriculture in the forest area. The recurrent fire contributes to global greenhouse gases, which accelerating climate change. Major gases emitted with forest fire include carbon dioxide, nitrogen oxides, volatile organic carbon, and particle matters. These gasses reduce the efficiency of ozone and release the aerosol into the atmosphere, which complex affects the cooling and warming dynamics of the environment. Worldwide, there have been increasing incidences of forest fire for few decades' results in environmental, economical, and ecological losses to natural resources.

KEYWORDS: ***Forest, Fire, Ecosystem, Environment, Climate change.***

INTRODUCTION

The global forest cover occurs in 31 percent of the total geographical area [1]. However, half of the forest cover is relatively intact, and more than 1/3 forest is primary forest (Table 1). The World forest area exhibit in 1.06 billion hectares accounts for 5000m^{2}per capita, which is enough for the environment's wellbeing. Nevertheless, the distribution of forests is not equal around the globe [2], and half of the world forest is confined to only five countries, namely the United States of America, Brazil, the Russian Federation, Canada, and China). Moreover, ten countries have two-thirds area of the natural world forests [3]. These forests are known as the earth's lungs as they provide environmental security by absorbing pollutants and harmful gases from the environment. The Amazon rainforest is the largest forest globally, followed by Congo and Atlantic forests (Table 1). The forest and its composition have different potentials of sequestering carbon results variation in CO_2 storage and their contribution in climate change mitigation (Table 2).

Table 1. The largest forest in the World

Forest	Area (km^2)	Countries
Amazon rainforest	5,500,000	Brazil, Peru, Colombia, Bolivia, Ecuador, French Guiana, Guyana, Suriname, Venezuela
Atlantic Forest	1,315,460	Brazil, Argentina, Paraguay
Congo Rainforest	2,000,000	Angola, Cameroon, Central African Republic, the Democratic Republic of the Congo, Republic of the Congo, Equatorial Guinea, Gabon
Daintree Rainforest	1,200	Australia
Kinabalu Park	754	Malaysia
Rainforest of Xishuangbanna	19,223	China
Sunderbans	10,000	India, Bangladesh
Tongass National Forest	68,000	United States
Valdivian Temperate Rainforest	248,100	Chile, Argentina

Table 2. Average carbon quantity sequestered by biome

Biome	Carbon quantity sequestered (%)
Tropical Forests	23
Tropical Savannas	18
Temperate Grasslands	17
Temperate Forests	15
Boreal Forests	11
Tundra	9
Wetlands	<1
Croplands	N/A

Currently, forest fires have emerged as a global environmental concern due to shifts in climate patterns, increased aridity, and varying warming trends across different regions [4,5,6,7]. Table 3 illustrates widespread occurrences of forest fires worldwide [3]. In many instances, these fires are anthropogenic, resulting in the destruction of millions of hectares of flora, fauna, and microbial communities. Forest fires release harmful gases and particles that significantly alter the chemical composition of the atmosphere and the Earth's ecosystems [8,9,10,11]. During these events, large amounts of CO_2 are emitted into the atmosphere, contributing to future warming [12]. These emissions pose threats not only to forests but also to human health [13]. The environmental impact of forest fires depends on various factors including weather conditions, chemical composition, dynamics of fire plumes, volume of gases emitted, and atmospheric conditions affecting the dispersion of emissions [14]. The composition of gases emitted varies widely based on factors such as fuel characteristics—such as structure, type, chemistry, loading, moisture—and fire behavior specific to different forest areas [15]. These fuel characteristics are significantly influenced by environmental conditions such as seasonal weather patterns affecting fuel moisture or human activities like nitrogen and sulphur deposition that alter fuel chemistry [16]

Table 3. Forest fire activity in the World in 2010-2020

Year	Fire name	Country	Area cover (in hac.)
2010	Binta Lake Fire	British Columbia	40,000
2011	Texas Wildfire Season	Texas	1,623,481
	Wallow Fire	Arizona and New Mexico	217,741
	Richardson Backcountry Fire	Alberta	707,648
	Las Conchas Fire	New Mexico	63,250
2012	Whitewater–Baldy complex Fire	New Mexico	117,148
	High Park Fire	Colorado	35,323
	Ash Creek Fire	Montana	100,000
	Long Draw Fire and MillerHomestead Fire	Oregon	291,250
	Mustang Complex Wildfire	Idaho	134,000
	Rush Fire	California and Nevada	127,701
2013	Quebec Fire	Quebec	250,000
	Rim Fire	California	102,520
2014	Carlton Complex Fire	Washington	102,000
	Northwest Territories fires	Northwest Territories	3,400,000
2015	Okanogan Complex	Washington	122,306
2016	Anderson Creek Fire	Kansas and Oklahoma	148,770
	Fort McMurray Wildfire	Alberta and Saskatchewan	593,670
2017	British Columbia wildfires	British Columbia	1,216,053
	Montana wildfires	Montana	524,000
	Thomas Fire	California	114,078
2018	Mendocino Complex Fire	California	185,792
	British Columbia wildfires	British Columbia	1,354,284
2019	Decker Fire	Colorado	3,626

2020	Colorado Wildfire Season	Colorado	240,000
	Oregon wildfires	Oregon	400,000
	California wildfires	California	1,788,832

STATUS OF FOREST FIRE IN INDIA

Forest fires have increasingly become a significant cause of forest degradation in India, particularly in the dry deciduous forest regions. This is exacerbated during the autumn and dry pre-monsoon periods when dry leaves accumulate and soil moisture levels are low, providing abundant fuel loads [17]. Forests in India are highly susceptible to fires, ranging from 33% in some states to over 90% in others [18]. Annually, approximately 3.73 million hectares of Indian forests are affected by fires [19,20,21]. In the north-eastern region of India, forest fires are often linked to traditional shifting agriculture practices [22]. Over 90% of forest fire incidents in India are due to anthropogenic causes, reflecting a reluctance towards forest conservation and protection [23,24]. Forest fires in India are caused by various factors including natural occurrences, intentional human actions, and unintentional or accidental interference [25]. Central and East-central states like Odisha, Chhattisgarh, and Madhya Pradesh, which are dominated by tropical deciduous forests, are particularly vulnerable to seasonal fires. In the Himalayan foothills, Chir Pine forests are prevalent and prone to rapid spread due to the resin content in these species [26]. According to the Forest Survey of India, 55% of forest fires are attributed to grazing activities, where fires are intentionally set by cattle owners to promote the growth of green grasses. Natural regeneration in areas affected by fires is reported to be 72% lower compared to non-fire affected forests [19]. Table 4 illustrates the incidence of forest fires in different states of India, highlighting significant forest losses due to frequent wildfires [27].

State	Fire affected (%)
Assam	51
Gujarat	51
Arunachal Pradesh	93
Bihar	67
Himachal Pradesh	69
Jammu & Kashmir	46
Karnataka	45
Madhya Pradesh	76
Meghalaya	94
Orissa	94
Nagaland	87
Utter Pradesh	58
West Bengal	33

COMPOSITION ON FOREST FIRE

Forest fires are intricate processes that degrade the carbon stored in plants and soil [28]. Emissions from forest fires include carbonaceous aerosols, greenhouse gases, CO, and other compounds. The presence of flammable fuel determines the intensity of a forest fire. Forests typically contain 35-55% carbon in their woody biomass, which is released into the atmosphere during burning [29,30]. Combustion of fuel releases a complex mixture of gases and particulate compounds such as CO2, NO, SO2, and other toxic and carcinogenic gases [31]. Different burning temperatures are required to combust various wood materials from plants, resulting in the release of diverse gases into the environment (Table 4) [32].

Table 4: Forest fire and its volatile products under different temperatures.

Temperature margins	Typical volatile products relies in forest fire
100-300°C	HX, HCN, H_2S, Monomers
300-400°C	NO_X, CH_4, C_2H_4, CH_3OH, C_2H_5OH, HCOOH, CH_3COOH, H_2CO, CH_2=CH-CHO, Furans, Ketons
400-500°C	Hydrocarbons C7-C10
500-600°C	Hydrocarbons C_{10}-C_{30}, BTX, PAH, Chlorinated Aromatic Compounds, PCDD, PCDF
More than 300°C	NO_X, Soot
All margin	H_2O, CO_2, CO, SO_2

EFFECT OF FOREST FIRE ON THE ENVIRONMENT

Mainly, forest fire affects all components of the environment; however, the most common impacts are described below:

i. Fire effluents in the water

Forest fires have been polluting the water, directly and indirectly, due to the formation of harmful chemicals by the fire, first going into the atmosphere later to the water by precipitation or sedimentation. In presence of ash, scale and small plant pieces can mainly cause the direst pollution in nearby surface water. Indirectly, the pollution has spread the long-distance by the wind causes polluting distance waters [33]. Forest fire is commonly extinguished with water, although uses in other agents depending on the type of fire [34]. Some many chemicals are produced after the fire that is soluble in natural water sources. One of the more specific pollutants is Polycyclic Aromatic hydrocarbons (PAHs), hydrocarbons, dioxins, volatile organic compounds (VOCs), ammonia, metals, and suspended solids that are also likely in the substance mixed in the water. In addition, water used for fire-fighting can wash other fire extinguishing chemicals into the neighbouring surface waters, polluting rivers and lakes in the vicinity [35]. Those neutral chemicals in soil and only change the chemical composition ratio but are otherwise inactive can be activated in water by a series of chemical reactions, causing dangerous pollution on much larger territories example, alongside a river. These pollutants can endanger or even exterminate water ecosystems [36].

ii.Fire effluents in the air

The fire plume has entrained products of combustion that move upward due to excess, where it will spread based on prevailing wind conditions [37]. In a forest fire, emitted gas may be present in the volatile organic compounds (VOCs), inorganic gases, the Polycyclic Aromatic Hydrocarbons (PAHs), and the dioxins. The species that are spread by the plume will be pretty light. The main hazards of these gases are the toxicity of the contents and the susceptibility of the receptors. For example, forest fires often will emit particulates that consist of soot and smoke particles. These particles are not highly toxic and dangerous to healthy populations but too susceptible populations such as those with asthma or respiratory in old populations [38]. A large number of organic microparticles in the atmosphere emanating from incomplete burning can pollute the air. During forest fires, vast quantities of carbon dioxide (CO_2) go into the atmosphere, aggravating the greenhouse effects growing tendencies accelerating global warming [28]. Because of forest fires, territories of woodlands and the number of trees reduce together their photosynthetic performance and oxygen production, making the situation even worse.Due to incomplete burning,they are causing severe health risks to animals and firefighters.

iii.Fire effluents in the terrestrial environment

The terrestrial ecosystem plays an essential role play in ecological conditions in the World. Forest fire impact on the terrestrial environment is less of a short-term hazard but might have long-term exposure concerns [17]. In increase, the quantity of the effluents to the terrestrial environment can be a primary pathway and a secondary pathway where effluents would be thrown from the plume down to the ground. Again, a critical part of the identification of the effluents will be whether there are any hazardous materials stored on-site and any extinguishing agents used. Polycyclic Aromatic hydrocarbons (PAHs), furans, dioxins, metals, and items that present some form of toxicity [39].

Iv.Cooling and Warming Effects

Mostly, whether the global level of fire activity in warming or cooling the atmosphere overall [40]. Fire flumes produce gasses like CO_2 and other volatile organic particles called aerosols, including substances like black carbon and gases that form ozone [41]. One recent study on the Environmental Protection Agency suggests that forest fires emit three times fine particle pollution than the Environmental Protection Agency estimated. This pollution creates an impact on the climate. Some of those aerosols can make the more reflective in the atmosphere. They also block the sunlight and cool the atmosphere, similar to the effect attributed to emissions from volcanic eruptions [42]. In general, the climate effect of aerosols is temporary, lasting from a few months to a couple of years. Nevertheless,black carbon, aerosol, and temporary climate pollutants can absorb heat while floating around in the air, which causes the atmosphere [43].

V.Wind-Blown Soot Can Affect the Ice Sheets

Few aerosols and other particles are heavy enough to drift earthward, and others will wash to the ground with the first good rains of autumn or winter, but not before spreading out over the Northern Hemisphere's oceans and continents[44]. Those tiny remnants of burned plants can also affect the climate when they land on mountain glaciers, especially on the Arctic snow and ice. In some years, scientists have traced soot from wildfires in Canada to Greenland, where they darken the ice and snow and speed up melting [45]. The overall effect of wildfire fallout on Arctic melting is difficult to quantify, partly because of sparse sampling across the remote area and the significant annual variations in wildfire emissions [46].

Vi.Environmental problems due to fire fighting agents

The various aspects of possible environmental pollution are caused by fires and fire-fighting agents [35]. The fighting fire substances influence the atmosphere, soil, the vicinity of the burning object, the groundwater, and the surface waters in very diverse manners [47]. Some fire fighting activities reduce the fire intensity, such as the heat of a fire, bursting tanks, vapour cloud explosions, etc. The contract of chemical reaction in a chemical reactor under a set of adequately controlled conditions, in under produce in hundreds of chemical compounds[48]. In the first-line present in water and carbon dioxide. Some released of other substances have a high toxic potential to men, flora, and fauna. Toxic and, in other ways, dangerous substances are brought into the soil of the fire ground by the fire brigade's activities [49]. If the fire brigade succeeds and provides a sudden quenching of the hot he with cold water, this will stop the chemical chain reactions at once. A chemical cocktail with an indefinite composition has evolved in a fire that is subject to a sudden fall in temperature and change of reaction medium due to the application of a fire-fighting agent. Primarily, Halons and FCFCs chemicals are used in the fire fighting agents. This agent major responsible for destroying the ozone layer in the stratosphere shows how environmental problems with a very efficient fire-fighting agent can take a global dimension [32].

IMPACT OF FOREST FIRE ON CLIMATE CHANGE

Fires are significant responses to climate change, but fires are not only a response. They feedback to warming, which feeds more fires.When vegetation burns, the resulting release of stored carbon increases global warming[50]. The excessfire releases more carbon dioxide and creates more warming and also more fires. The very black fine carbon soot, released into the atmosphere by fires, also contributes to warming [51].Forest fires affect the global carbon cycle, and thus the climate, in three main ways [52]. Forest, fire releases large quantities of black soot carbon into the atmosphere through the combustion of plant material and surface soil organic matter. Second, fire-killed vegetation decomposes over time, emitting carbon [53]. Third, the vegetation on newly burned sites may not absorb as much carbon from the atmosphere as the decaying vegetation emits, or as much as the prefire vegetation absorbed, for several years or decades after a fire. Some everyday activities that influence climatic are:

i.Fire i. As a Source of Greenhouse Gases

According to the Intergovernmental Panel on Climate Change [54,55] Greenhouse gas is an increase in an atmosphere responsible for forest degradation and associated biomass burning. Forest fires have contributed significantly to greenhouse gas emissions, influencing global climate change [56]. The significant contributions to global fire emissions are from Africa, South America, Equatorial Asia, the boreal region, and Australia (Table 5) [57]. In carbon emission, savannas and grasslands contribute 60%, but most of these emissions compensate by rapid post-burn regrowth [58]. Fire is also an essential source of aerosols. Aerosols decrease regional and global irradiation through the backscattering of incoming solar radiation [59]. Smoke aerosols can also decrease or increase cloud cover in complex and nonlinear ways that are not yet adequately quantified. A forest fire can also influence the radiative forcing by altering the albedo [60]. To release the black soot immediately after a burn heats the surface by reducing albedo. However, fire-induced reduction in tree cover can cause cooling by extending snow cover in boreal forests or replacing dark forests with more reflective vegetation (eg. savannas grasses) elsewhere.

The net effects of changing forest fire regimes on global warming are complex and uncertain.

Table 5. Major contribution to global fire emission

Africa	52%
South America	15%
Equatorial Asia	10%
Boreal region	8%
Australia	7%

ii.Fire as a source of global worming

One of the major culprits of climate change is forest fire. The burning of forests also destroys an important sink for atmospheric carbon dioxide. Hence the significant role of forest burning in the World's carbon dioxide budget. If the burned ecosystem regrows, the carbon dioxide is eventually removed from the atmosphere via photosynthesis and is incorporated into the new vegetative growth. Other gaseous emissions, however, remain in the atmosphere. Studies suggest that biomass burning has increased globally over the last 100 years, and calculations indicate that hotter earth resulting from global warming will lead to more frequent water-related calamities and larger fires[61].

iii.Fire as a source of ozone layer depletion

Ozone (O_3) is an essential secondary air pollutant with health and climate implications [62,63]. Exposure to high ozone concentrations has also been linked to short-term mortality [64], aggravates bronchitis and irritates lungs, asthma, and emphysema [65,66]. Ozone forms from the interaction of non-methane organic carbonsand nitrogen oxides in the presence of sunlight. There are good natural sources of nitrogen oxides, and non-methane organic carbons are typically the limiting precursor in ozone production. Wildfires also generate substantial emissions of ozone precursors [67, 29], and the majority of observations suggest some degree of ozone production from wildfires. Wildfires emit substantial amounts of non-methane organic carbons and nitrogen oxides, the primary ozone precursors. In identifying the large number of non-methane organic carbons has been smoking plumes68].However, the boreal regions have found that ozone is minimally enhanced or even depleted downwind of some biomass burning of plumes [69].

Iv.Changes to biodiversity

Forest fire is one of the most primary causative natural drivers of biodiversity loss[70], depletion of terrestrial ecosystem productivity and exhaustion of forest carbon stocks [71], the decline in soil fertility, and subsequent crop production [72], escalation of air pollutants [73], water quantity and quality [74], and increase in the magnitude of landslide susceptibility [75]. After the forest fire species change in composition, this may be good or bad depending on the utility of the stands that preceded and succeeded the fires [76]. In forest ecosystems, understory fire regimes have the most significant influence on biodiversity within plant communities because the understory vegetation is more affected by fire than the overstory [77]. Stand-replacement fire regimes substantially influence biodiversity across the landscape by affecting patches' size, shape, and distribution. Mixed fire regimes probably have the most influence on biodiversity within plant communities and affect patch characteristics or community diversity. Fire frequency and seasonal timing largely determine biodiversity in grassland ecosystems. In many ecosystems, biodiversity can be increased after the fire and reduced by eliminating fire [78].The most diverse complexes of species in various fire regimes in time and space creatures. The ecosystem diversity is landscapedafter a fire with high timing, pattern, intensity,and frequency[79].

v.Ecosystemdestruction

A forest fire has been destroying the forest ecosystem and decreases the species population in the forest. The ecosystem's most destructive causes of forest fire are very evident in the Himalayas area, where the Himalayas region's pine forests are dominated in 1000 to 1800 meters of height and seem to be more fire-prone [80]. Most of these forests have preceding fire history repeated fires have converted mixed forests of oak and Chir to pure chir forest. Mostly, Chir pine is planted in this area, but most of the principal reasons for the conversion of mixed forest of Chir and oak is a repeated and uncontrolled forest fire [81]. In the oak forests, uncontrolled fires have made the less favorable situation for the growth and more favorable for Chir forest growth. The uncontrolled fires in such areas help spread pine forest at the cost of indigenous oak forest, which is a grave threat to the ecological balance in the Himalayan region [82].

CONCLUSION

A forest fire is crucial for ecological conditions because they disturb forest ecosystem and climatic conditions of the area. It releases many trace gasses and particles; these gasses are very significant responsible for changing the chemical properties of the atmosphere and global ecological system. The emitted gasses adds various substances such as carbon monoxide, carbon dioxide, nitrogen oxides, particulate matter to the environment and contribute to the global warming. These gasses are primarily responsible for influencing the environmental condition and greenhouse emission, which indirectly influences the albedo and ozone formation effect. Fire also emits aerosol in the environment, which is responsible mainly for the cooling and warming of the environment. Release the emitted gases or particles significant role play contribution of increase the air pollution in the environment and decreasing visibility in a particular area.

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