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Elevation in wildfire frequencies with respect to the climate change

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A R T I C L E I N F O

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A B S T R A C T

Forests have been undergoing through immense pressure due to the factors like human activities; procurement of forest products and climate change which is a major factor influencing this pressure buildup on forests. Climate change and temperature increase caused by anthropogenic activities have notably affected forests and wildlife on a global scale. High temperature increases the soil-water evaporation, resulting in drier soils, and water loss in forest flora. The incidence of forest fires has doubled since 1984 and these are linked to global warming. Drought influences fuel moisture by bringing about physiological changes in forest vegetation leading to forest fires. Forest resilience is hampered because of temperature and drought stress at the developing stage of plant's life cycle leading to the shift in plant species in those areas. Forest fire incidences can be managed with proper management strategies such as sustainable, community and urban forest management. A careful monitoring of stress precursors, subsistence uses of forests, ecological education and planting of near native and new indigenous plant species are the tools that can aid in efficient forest management.

1. Introduction

Forests cover more than 30 % of the terrestrial ecosystem which in total count 4.06 billion hectares worldwide (FAO and UNEP, 2020) (Fig. 1). Forests are broadly categorized into three zones i.e., Tropical, Temperate and Boreal, and each has their own role to play for the maintenance of planet's ecosystem and bear the growing pressure in them as well. They assist in the provision of ecosystems for biodiversity and play a significant role in the conservation of plant and animal species (Gibson et al., 2011). In a study by Vié, Hilton-Taylor and Stuart (Vié et al., 2009),it has been reported that 80 % of the amphibians, 75 % of birds and 68 % of mammals find their abode among forests. More than 60 % of the vascular plants can be found in the tropical forests. Along with plant and animal species, humans also deeply depends on forests for their permanence and this alliance dates back to the human species dwelling in savannahs and forests (Roberts, 2019). More than 1.6 billion people are dependent on forest resources for their survival as they contribute to achieving UN SDGs through mitigation of climate change and global warming in terms of energy, water, carbon dioxide exchange with the atmosphere. Forests store up to 45 % of the global carbon and produce 50 % terrestrial carbon (Field and Raupach, 2004). Immense use and over exploitation have affected the forest ecosystem and the strategic management can help to mitigate the climate change.

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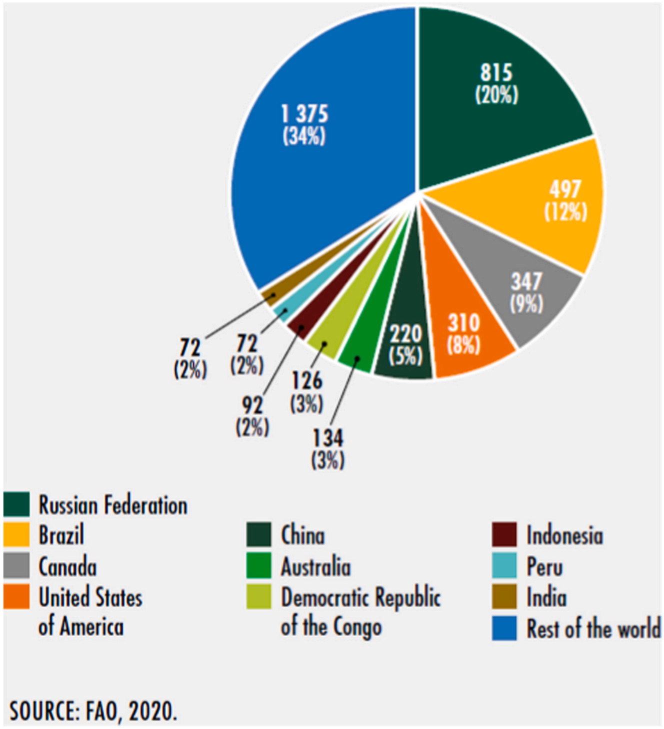

Fig. 1. Global distribution of forests in million hectares and percentage.

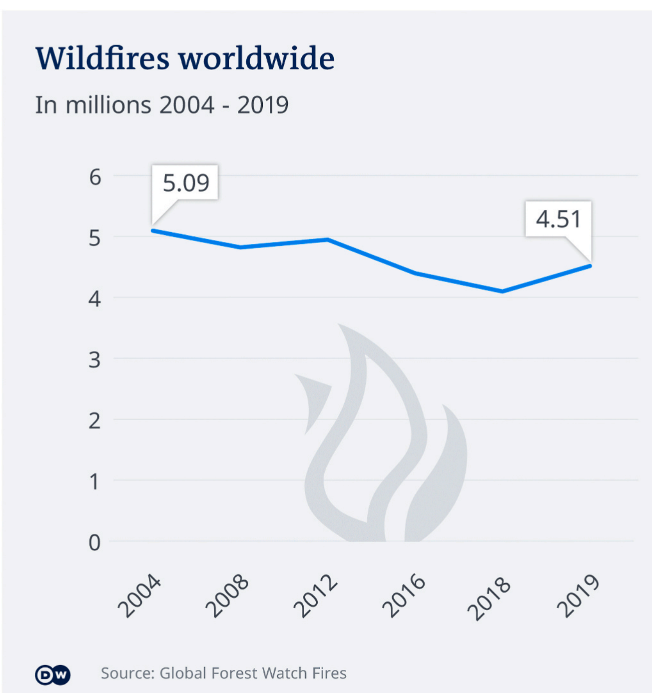

Fig. 2. Global wildfires incidences from 2004 to 2019.

2. Anthropogenic pressure on forests causing increase in global warming

Increased anthropogenic activities like urbanization and agriculture demand have lead to the immense pressure on forests over the last couple of decades (Laurance et al., 2014). Anthropogenic activities linked to the climate change have been important players in causing pressure over the forests and creating the negative impact on a global level (Siegert et al., 2001). During the years 1980–2000, larger portion of agricultural area was created by clearing the forests across the tropics (Gibbs et al., 2010) and this practice is increasing since then. A loss of 129 $\times$ 10^6 ha of forest area has taken place worldwide, due to deforestation between the years 1990 and 2015, which is approximately of the size of 122 million km^2 indicating a net loss of 0.13 % per year (Zhang et al., 2020a). The global population has doubled since 1950s and is likely to reach 9 billion in 2050. Poor forest management and impaired forest laws have led to improper deforestation in the name infrastructure development and expansion of cities thus increasing the human interference into the forests ultimately resulting in juvenalization, monotypization and neophyzation leading to the changes in forest plant communities (Pedrotti, 2013). Human dwellings around the forest areas have affected biodiversity with changes in ecological processes resulting in separation and division of species populations along with a major genetic drift among the patches of forest fauna and flora. Colonization in smaller habitats is also the cause of higher rates of the extinction of the wild species (Ledig, 1992). Human caused wildfires create pressures on forests leading to alteration in habitats, shifting of the species and conversion of forests into grasslands (Nunes et al., 2016). The continuous transformation of Amazonia of tropical forests into the grasslands has caused the temperature increase in that region. In a similar way the changes in the tropical forests of Asia and Africa have influenced to extratropic as well. These forests have low albedo and more net radiation and evapo-transpiration mainly during the warm season. Being vulnerable to the drier climate, these can further worsen the already alarming situation of global warming. Amazonian forests were cleared at the rate of 25,000 km^2 per year (Malhi et al., 2008) during 1990's and on a global level tropical forests faced a loss at the rate of 152,000 km^2 per year (Hassan et al., 2005). The bio geophysical effects of the boreal forests are said to be highest among all the biomes globally These forests have much higher carbon storage in soil and wetlands 2004) thus contributing to the carbon sink in Northern Hemisphere (Solomon et al., 2007). Boreal forests are at risk due to the increasing global warming. Although these can have the capacity to expand and transform into tundra but eventually are expected to die back. Boreal forests mainly contain conifers and evergreen trees which can be shifted to deciduous forests. Older trees are on a risk due to the insect infestation and increasing wildfire incidences which can lead to the shift towards younger age class of trees causing the shifts in biome years despite the low contribution of boreal forest in worldwide biomass burning emissions (Yadav and Devi, 2018). Similar pressures are faced in temperate forests as well where large portion of it has been cleared for agriculture purposes. Temperate forests contribute to 20 % of biomass of the world and 10 % of terrestrial carbon.

The air pollutants (SO2, Nitrogen oxides and particulate matter) and soil pollutants (heavy metals and acid accumulation) emitted from industries and urban areas are the cause of mortality and replacement in forest species leading to habitat transformation and biodiversity loss and disturbance in soil dynamics (Ledig, 1992; Hauck et al., 2013). Climate change due to human activities has led to the overall increase in global temperatures and deterioration of soils leading to drought conditions that are the main reason for wildfires forming one of the reasons of global warming thus creating a loop. According to IPCC, northern latitudes experiences record warmth because of anthropogenic forcing. In Portugal, Parente et al. (2019) successfully detected the drought impacts on the occurrence of wildfires using one of drought indices called Standardized Precipitation Index (SPI). They were able to find that 97 % of large wildfires and 98 % burnt areas happened during drought between 1981 and 2017. The outbreak of insect pests like beetles can also be considered one of the important factors leading to the destruction of 35 million hectares of forest area per year. The insect infestation can be correlated with the increase in global temperature (Van lierop et al., 2015) such infestations pose a threat to health, sustainability, productivity and resilience of the forests.

Mostly the human land use (agriculture and residential purposes) has put these forests to risk and growing population could create more pressure on them and pose an increased threat to these forests. Increasing the fire risks make forests more stressed by climate change (Xu et al., 2020). Although forest fires have been recognized as an important environmental activity influencing the ecological balance since the existence of the earth, but the increasing human activities and climate change have caused a spike in the incidence of these fires at a higher rate due to which these incidences have doubled since 1984 and can be directly correlated with the human induced climate change (Abatzoglou and Williams, 2016). The climate change caused due to human interferences in nature brings negative stressors like drought conditions; pest infestation and increase in lightning strikes ultimately leading to destructive wildfires.

3. Factors responsible for wildfires

There are various other factors that are indirectly linked to climate change and are rendered to be the causes behind wildfires. Lightning is responsible for one-third of the forest fires from May to September each year (summer months) and is also associated with global warming. It has been estimated to increase by 12 % with each degree rise in temperature (Romps et al., 2014). Moris et al. (2020) illustrated a methodology to link fires and natural lightning. They recommended a fixed maximum 10 km radius and 14 days of holdover time and found that identifying igniting lightning is required to advance the knowledge about lightning-caused fires. During the fire succession in the fire affected areas, the releasing and consumption of Greenhouse gases may be altered because of changes in physico-chemical and biological soil properties leading to change in their capacity to sequester carbon. Adkins et al. (2019) found that wildfire severity influences not only soil C but also nitrogen pool and less soil C is stored in areas of high fire severity. Fuel moisture is also identified as great component for fire incidences (Turco et al., 2017). The ignitability of the fuel beds and temperature of the heat source affect spreading the wildfire via a fire ladder. Also, the engagement of soil organic carbon in wildfires (Fig. 3) can assist the spreading of fire from one vertical fuel layer to another. Such fire ladders are more expected near the forest-tundra ecotones.

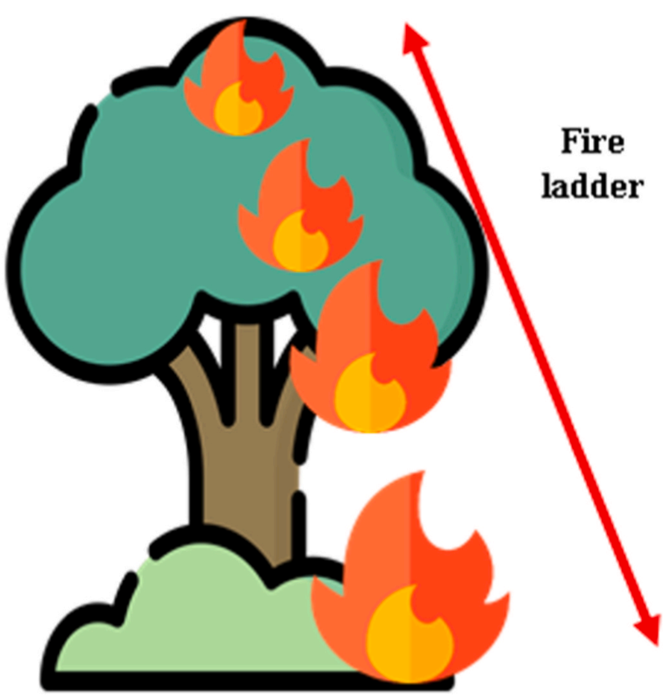

Fig. 3. Schematic diagram of a vertical fire spread via fire ladder from trees and shrubs to soil and vice versa.

This can be due to the self-pruning of lower branches is reduced leaving many branches that touch the soil surface (Blauw et al., 2017). It is urgently needed to predict the rate of spread (RoS) and the intensity of wildland fires to have a sustainable management plan. Moinuddin and Sutherland (2020) simulated the extend of the grassfire (surface fire) to single-tree fire beside studying the transitions of surface-to-crown fire. They worked on two groups of 2.25 m height trees to be ignited by a natural gas burner (30 kW). Each group had ~14 % and ~49 % average moisture content by mass. Two physics-based models were adopted to simulate tree burning: Wildland Urban Interface Fire Dynamics Simulator (WFDS) and Fire Dynamics Simulator (FDS). They concluded that the crown fire is supported by the surface fire because the surface fire continues to spread at roughly the same rate as the crown fire.

Drought factor should be considered as it effects on vegetations and forests can be easily assessed than other environmental drought effects especially with the availability of remote sensing (Byer and Jin, 2017). The frequency and extent of forest fires are clearly controlled by drought because of reduced precipitation, vapor pressure, increased temperatures, and wind speeds which results in more flammable fuels (Vicente-serrano et al., 2020). The high temperatures and low relative humidity are the key for wildfire ignition. In the future, wildfires can be estimated based on projections of future temperature and precipitation. Such projections can be simulated from the relationship between observed climate and the burned area over the last 100 years (Halofsky et al., 2020). Fig. 4 illustrates a conceptual model for indirect and direct effects of climate change which cause shifts in vegetation. Davis et al. (2017) projected that the forests with area >40 ha are highly susceptible for wildfires and will increase by >20 % in the next century for most areas in USA. Unsustainable management of forests led to the loss of forests which modifies regional climate so can increase fire susceptibility. Xu et al. (2020) indicated that Amazonian forests experienced high losses and are more susceptible to fire. When 80 % of the forest cover is lost, the region is susceptible to more than 40 % increment in fire.

4. Global scenario of wildfires

Global Forest Watch counted more than 4.5 million fires worldwide in 2019 (Fig. 2). Fires caused due to human activities like campfires, fireworks and burning cigarette butts burn hectares of forests including its vegetation each year. A global evaluation conducted for the years between 2003 and 2012 has recognized 67 million hectares of burnt forest land per year (Van lierop et al., 2015) and the year 2015 witnessed 98 million hectares of burnt forests around the globe being the hottest year of the decade (FAO and UNEP, 2020). Most affected forests were tropical forests where about 4 % of the total forest area in and around South America and Africa was hit with the disaster. The wildfires that caught the public eye in a dramatic way were the ones that occurred in Australia, Greece, Brazil, Russia and California in 2018–2020 and is reported to be responsible for losses of human as well as animal lives, properties and infrastructure along with drastic environmental, ecological and economical losses.

Global Annual Burned Area Ampping (GABAM) based on a Landsat data (Long et al., 2019) has revealed that total area burned in the years 2000, 2005, 2010, 2015 and 2018 the average value of burnt forests in the world was 82.09 million hm^2. Zhang et al. (2020b)in their study reported the statistics of the burnt down forests in each continent and according to the climatic zones from the year 2000–2018 indicating that tropical areas were the ones with more wildfire incidences which mainly included the parts of Africa and South America.

The wildfires have a major impact on the infrastructure and the wildfire events have proven to be responsible for structure as well as human and animal lives. Most of these destructive events are caused by human activities, and with the increase in population, the human dwelling is being pushed towards hazardous forests that constitute wild land-urban interface (WUI), thus the problem of structure and human

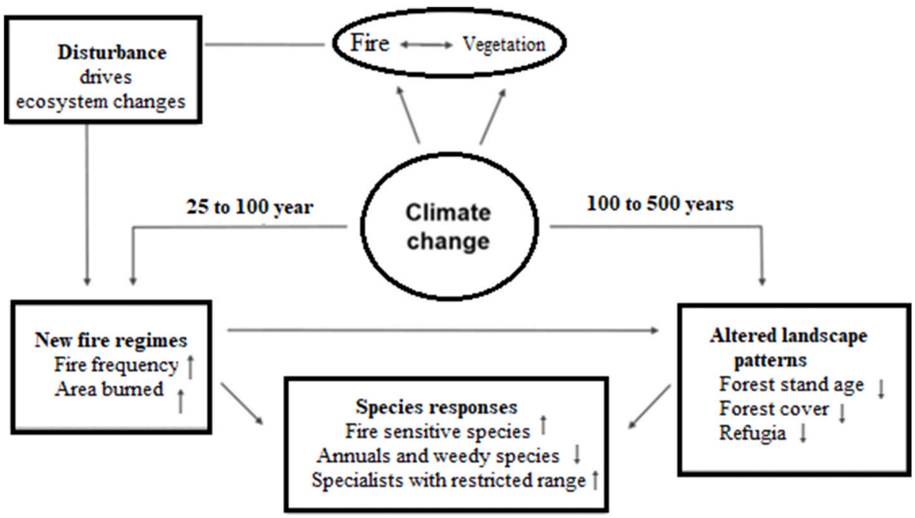

Fig. 4. Schematic model displaying that indirect effects of climate change via disturbance cause faster shifts in vegetation than direct effects of climate change. Adapted from (Hlofsky et al., 2020).

loss is getting worse. The ignitions being human caused wildfires occurrences are more likely to take place with WUI expansion (Nagy et al., 2018). The destructive wildfires that have claimed many lives and caused infrastructure loss have been occurring all across the globe such as Australia, Europe, Russia, Portugal and California (Molina-Terrén et al., 2019; Shvidenko and Schepaschenko, 2013; Viegas, 2018; Syphard and Keeley, 2019).

With a recent increase in the incidences of wildfire activities, concerns about more rise in forest fire occurrences and the damages and loss that they bring along are increasing. A study has determined the future trends based on the trends in past millennium fire activities using the various simulation models. The fire activities are projected to get increased around the globe with variations from area to area with consistency in the patterns of biomass burning trends (Pechony and Shindell, 2010). Therefore, wildfires constitute a major natural hazard. These incidences can however be reduced with the government-imposed regulations for restrictions of infrastructure development near and around forest areas which would reduce the wildfire incidences and thus reduce the loss.

5. Recommendations

5.1. Forest management

The concept of sustainable forest management has grown inclusively of various complex dimension. Management of forests starts with the trees and extends up to streams, habitat and watersheds, wildlife, and even the rotten trees or logs on the forest floor. Presently, millions of hectares of forests are being managed according to the principles of sustainable forest management. These practices are being adopted in North America, Europe, and around the world Forest management syndicates an overall comprehension of environmental process with site-specific knowledge to endure forest ecosystems. Throughout the world, the countries have developed National and International criteria and indicators that can monitor and measure the goal for achieving sustainable forest management (MacDicken et al., 2015). To the extent of such criteria, the Montreal Process (Montreal Process Liaison office, 2000) is an international framework used as an approach towards the progress of sustainable forest management. The seven criteria given by the Montreal Process enables to achieve the sustainable forest management goal. These criteria are; bio-diversity conservation; to maintain ecosystem productive; to maintain health and vitality of forest; soil-water conservation; carbon cycles maintenance by forests; socio-economic enhancement and maintenance to fulfil the requirements of societies and to develop the legal, economic and institutional structure for conservation and sustainable management of forests. Similar kind of criteria and indicators were also adopted by Helsinki Process in Europe and International Tropical Timber Organization.

Over the past years, traditionally, forests have been managed by local communities. As noticed, community forest management has emerged as one of the main strategies, implemented by many developing nations at various stages of forest development (Resosudarmo et al., 2014; Rasolofoson et al., 2015, 2017). However, for the preservation of our natural resources, the concept of sustainable forest management (SFM) or proper forest management came into existence. Despite of the fact that there is no generally accepted definition of SFM, it can be referred as the process of strategically managing the forests keeping in consideration the production and derivation of the forest products and services without any disturbance to the productivity as well as to the environment (Castañeda, 2000; ITTO).

Programs and their criteria for sustainable forest management.

i. ITTO Program: Enabling the condition and situation of forests, their health, production, biodiversity conservation, soil-water protection, and maintenance of social, economic and cultural aspects of the forest ecosystem.
ii. MCPFE Program: Contributing towards global carbon cycle by maintaining and enhancing forest resources, maintaining the health and vitality of forest ecosystem, encourage the production of timber and NTFP's, biodiversity conservation, proper management practices, and maintaining socio-economic conditions.
iii. MONTREAL Program: Biodiversity conservation, build-up the productive capacity of forest ecosystem, maintaining the health and vitality of forest ecosystem, soil-water conservation, maintaining the global carbon cycle, enhancing long-term socio-economic benefits, and proper application of legal and institutional framework.

5.2. Sustainable management of forests at global level

MacDicken et al. (MacDicken et al., 2015) analyzed key indicators enables to achieve progress for implementing SFM at global and regional level. To implement the enabling conditions for SFM, and to provide insight into the current progress, country's Global Forest Resources Assessment 2015 (FRA) report data was used. As per government reports, it was seen that, more than 2.17 billion ha forest area of the world remains under permanent forest land use, out of which around 1.1 billion ha were covered by SFM tools investigated in FRA 2015. At the global scale, it was seen that policies and regulations related to SFM were reported to cover around 97 percent of total forest area. While the number of countries with forest inventories at national level were improved over the past years. Only 37 percent of forests in countries with low income were covered by forest inventories. Forest management and monitoring of plans were augmented significantly, as was forest management certification, which surpassed a total of over 430 million ha in 2014. As of 2014, 90 percent of forests in boreal and temperate climatic regions were certified, while only 6 percent of permanent forests in the tropical domain were certified. The outcomes of the study revealed that profundity of work is desired to establish the conditions that support SFM over the longer period and suggests that these practices should be implemented where they are most needed.

As SFM is growing with people's consciousness and advanced technical knowledge, the concept of sustainability must also be renewed and the past references should be avoided. Therefore, criteria and indicators need to be updated constantly to monitor and report progress on SFM and to ascertain the changes in forest management practices in order to sustain and improve the health of forests (Keenan et al., 2015). The various limiting factors as per technical point of view include lack of training of officers and technicians and responsible for reporting, assessment and, monitoring of C&I for SFM, chiefly vis-à-vis upcoming or new issues, such as degradation and deforestation of forests, loss in management and conservation of biodiversity, carbon sequestration, forest restoration of landscapes, protection of watershed and related programs such as REDD+ and other global initiatives (González et al., 2010). The absence and dispersal of time-to-time information regarding forest resources and lack of synchronization between GIS and distinctive FRI's (Forest Resource Inventories) are also inappropriate (Linser et al., 2018).

5.3. Home and societies management near forests

Management of woodlands with the focus on promoting societies and communities in nearby forests is community forestry. Productive purposes of the forest had fascinated various stakeholders, including public, private, and local forest operators towards management of forests. These stakeholders have a distinct interaction with forests to satisfy their socio-economic and political needs. Forest User Group (FUG) manages and controls the local forests in societal forestry. The executive committee elected by forest user group assembly harvests and assesses all forest products and their management (Anup, 2016; Gilmour and Fisher, 1998). Native people gain affiliation and receives cash subsidy as an incentive for sustainable management of forests after registering in District Forest Office (DFO). Superfluous income received from Community Forest User Group (CFUG) was used for the purpose of infrastructure development (Anup, 2016) Therefore, to obtain the co-operation and to take the necessary actions related to forest management, the authority should be given to the people near forests (Gilmour and Fisher, 1998).

In home and societal forestry, sustainable management of forest is done to safeguard natural resources and forest ecosystem functions. It can also generate income opportunities to local residents from conventional and non-traditional products and services. These services and benefits received from forests include NTFP's, watershed protection, recreational, ecotourism, carbon sink, aesthetic and religious, genetic resources, medicinal and ornamental plants and wildlife habitat (Brendler and Carey, 1998). Despite of the merchandize value from wood and NTFP's, non-merchandize values include environmental stability, aesthetic and the economic stability. Home and societal forestry is performed on government forest lands, with partnership and harmonization between local communities and forest landowners for economic development. Joint forest management is to be taken into consideration when forests are managed by the local communities.

To achieve the goal of sustainable forest development and output, forest communities must be participants in forests management process. The involvement of local communities is crucial for sustainable management and development of forests. This is owing to the fact that they are best acquainted with forests and can easily identify the problems related to forest management, in relation to their needs and aspirations and will always be delighted when they are given the opportunity to participate. In addition to that, good education and information to villagers and forest residents about SFM are compulsory for proper and sustainable utilization of natural resources (Jurin et al., 2010). This creates in them, the sense of recognition and belonging. To get the attention of the forest communities towards forest management, adequate funding security of their long-term rights, prevention against conflicts, capacity building in collaboration with the local government needs to be assured. This will help to create awareness in the communities and assemble them towards achieving the goal of sustainable forest management and development.

5.4. Forest development

Urban forestry is not a new concept, but now-a-days, it is one of the growing potential concepts around the globe. It is of utmost importance to comprehend the subtleties of planted indigenous forests to rehabilitate them efficiently (Oldfield et al., 2015; Wallace et al., 2017; Miller et al., 2017). This is deprecatory for urban forests in particular as they provide various benefits, such as environmental services (Dobbs et al., 2011; Endreny et al., 2017), enhances well-being and health of humans (Alberti, 2005); and retreat for endemic biodiversity (Aronson et al., 2014).

As the urbanization increases, the integration of trees into urban areas also increases to such an extent that the trees managed in urban areas is studied as a distinct discipline of forestry. The concept of Urban forestry came in the late 1960s in North America, and grew out of what was mostly termed as environmental forestry (Miller et al., 2015). The sustainable management of forests in urban areas may be may be approached from two broad perspectives, one that there should be focus upon the trees themselves, the prospective benefits which we get from them, their major threats and problems in their cultivation. Another perspective, is to focus on the residents, their needs and the nature of their living conditions, and then to consider how trees might be of benefit to them.

Management strategies given by United Nations Forest Services for Eco-regions, States and Nations includes the concepts of established forest land base maintenance which holds the strong sustainability position and stresses on the fact that goods and services provided by forests are inimitable. Thus, human-created principal is no supernumerary for forest land. Similarly, loss of northern forests cannot be fully remunerated by counteracting gain in forest areas in other parts of the United States or the World. There should be an increase in the forest biodiversity of indigenous flora and fauna, diversity in forest ecology and habitat across the landscape, and gene diversity of plants and animals related with forest. Also, a prominence should be given to restore the species and habitats that are threatened with extinction, and to control invasive species. Diversity in the size of forest structure and species composition on the landscape has to be maintained, since forests change constantly, but their trajectory of change is periodically altered by fire, invasive plants, insects and diseases, harvesting and harsh climatic conditions. Vigorous trees and diversity of forests can better survive with such disturbances and continue to function as forests.

The quality and quantity of water, soil productivity should be maintained and minimization of soil erosion and contamination should be taken into account. Maintenance and increase in the capacity for sustained yield of wood and non-wood forest products should be employed for economic development. Forest based employment and community involvement is one of the major goals to be attained as mercantile ecological operations may be the most efficient means of varying the composition and structure of forests to achieve various goals, such as restoration of the habitat, reduction in hazardous fuel, and extenuation of hostile species. Enhancement of the standards of forest recreation and peoples need, so that they could have better knowledge to experience forests. Various policies, institutions, guidelines, and inducements that support sustainability of forests at numerous scales should be maintained in order to upsurge environmental literacy and involvement of a variety of stakeholders in sustainable forest management.

6. Conclusion

Planet has been undergoing through immense pressure due to anthropogenic activities leading to global warming and climate change to which forest fires are one of the major outcomes. Forests around the globe have been going through a major disturbance due to higher occurrences of these fires. The reduction in the wildfire incidences can be achieved through various strategic management systems. There should be a careful monitoring of the precursors of stress that cause fires. Tree species also need to be monitored as they have a remarkable capacity to protect themselves against threats. To achieve better-quality understanding of the forest and its practice for better management and monitoring, knowledge and information gaps for should be filled, improved technologies in management should be introduced and proper monitoring of the activities needs to be carried out under the strategic plan.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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