A review of forest fire and policy response for resilient adaptation under changing climate in the Eastern Himalayan region

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ABSTRACT

This review paper presents the extent and magnitude of forest fires and adaptation responses to deepen our understanding of the dynamics of forest fires in the eastern Himalayan region. We used a narrative scooping review approach to narrate the present state of forest fires and resilient adaptation responses to guide the development of climate resilient adaptation pathways in the future. Our review concludes that forest fires (total mean fire incidence = 3,158.5) continue to destroy overwhelming areas of forests every year (mean area destroyed = 658,778.4 hectares), presenting significant threat to ecological integrity, human wellbeing, and global effort to fight climate change. Fire incidences are highest during and post dry winter months which quickly declines at the onset of monsoon. Adaptation and responding to ever growing size and frequency of forest fires are limited by lack of awareness, training on fire management, firefighting infrastructure, technology, and adequate policy and financial support. In addition, there is acute lack of scientific studies to understand forest fire dynamics in the eastern Himalayan region. Based on the forest fire literature we argue that policy makers and communities must quickly adopt policy strategies that support smart responses to forest fire management including allocating adequate funds to support capacity building and research. Such decision must be based on research into potentials for climate resilient pathways for adaptation response.

1. Introduction

Forest fire is one of the major environmental disasters that has serious consequences for ecosystem services, biodiversity, and humans (Babu et al. 2016). Globally, forest fire continues to destroy large areas of forests each year (FAO 2020). According to the data from University of Maryland, USA, forest fire destroyed about 27.9 million hectares (ha) of forests in 2016 alone (Weisse and Goldman 2017) and the figure is increasing yearly. Forest fire can originate from anthropogenic or natural sources such as lightening, rockslide, and volcanic eruption, (Kim et al. 2019). Anthropogenic fires can be intentional or unintentional (Palit 2019). Traditionally, forest fire is an important process in driving ecological succession by serving as an environmental filter, species and traits selection, and determining ecosystem communities (Parashar and Biswas 2003; Satendra and Kaushik 2014; Aponte et al. 2016). However, too frequent fires burning out of their historical range can cause irreversible changes to the landscape and its ecology (Cha et al. 2020). When this happens, forest fires not only destroy living forest vegetation and wildlife but also decimate dead vegetation and debris, thereby exposing the top soil to erosion not to mention of the of the large quantities of carbon dioxide released into the atmosphere that exacerbates global warming affects (Hanson and Ranganathan 2017). The magnitude and extent of the impacts of forest fires can vary depending on the physical features, weather conditions, and forest types (Kunwar 2006). For instance, the impact of forest fires on vegetation differ by frequency, magnitude, extent, season, phenological state of the vegetation, combined effects with other disturbances such as storms, diseases, and pest attack (Palit 2019).

Unfortunately forest fires have become more frequent and devastating in recent years inflicting significant human, economic, and ecological damages (Parashar and Biswas 2003).

According to a study by (Alexander 1993), more trees are burnt by forest fire than any other natural disaster such as insects, parasites, frost, etc. Studies have also recognized climate as a major factor influencing fire patterns (Marlon et al. 2008; Flannigan et al. 2009; Aponte et al. 2016; Abrha and Adhana 2019). According to Abrha and Adhana (2019) increasing temperature, reduced precipitation, and drought in particular are responsible for increased frequency of forest fires. Such rapid loss of forest to fires can exacerbate the extent and magnitude of socio-
ecological consequences including shortage of fuel wood, displacement of people, degraded ecosystem services (Han and Han 2020), which are critical resources for wellbeing of humans and biodiversity alike. Where people are highly dependent on natural resources as in the Eastern Himalayan region, loss of forests and ecological services have been linked to poverty especially (Satendra and Kaushik 2014). Under such circumstances, the impacts are also felt disproportionately by the vulnerable groups. For instance, most women and children are engaged in collection of fuel wood and non-wood forest products, which are becoming more scare due to fires making their tasks more difficult (Sudhakar et al. 2014). An efficient fire management system is critical to manage and control forest fires and alleviate social, ecological, and economical difficulties inflicted by forest fires (Sudhakar et al. 2014). Some of the existing common management systems that responds to forest fire and fire related disasters in the study area include prescribed burning, early warning, fire breaks, and community-based management of forests and forest fires (Satendra and Kaushik 2014; Sudhakar et al. 2014). Prescribed categories of light fires of creeping types and ground fires in the forests helps to reduce fuel loading and hence minimize the chances of high intensity wild fires. However, such efforts especially in the Eastern Himalayan region are limited by human resources, economic ability, technical capacity, rough mountainous terrain, access, lack of efficient coordination amongst the stakeholders, and policy environments (Kunwar 2006; Sudhakar et al. 2014; Palit 2019; Tshering et al. 2020). In addition, these tasks are complicated by lack of scientific understanding of forest fire dynamics and uncertainties of climate change (Sharma et al. 2014). Consequently, Lim et al. (2019) stressed the importance of adaptation responses to manage forest fire related disaster risks.

These complex and interwoven issues beg for a need to deepen the understanding of climate induced disasters (its causes, affects, and impacts), resilience, adaptation policy responses, and the influence of climate change and environmental factors as accelerators of disaster risks in order to carve out resilience adaptive pathways. While there is a growing academic literature around forest fires, climate change, and adaptation, these are mainly concentrated in developed countries such as North America, Australia, South Korea, and EU. Only a few academic studies are available in the developing nations especially in the remote Eastern Himalayas and most of these are area specific. For instance, there is no publication that has focused on assessing the frequency of fires and the total area burnt at a landscape level across the Eastern Himalayan region, not to mention of the efforts to relate forest fire frequencies to changing climate. Such a study, if available will immensely benefit researchers and managers: (i) to get an integrated view of forest fire dynamics and disaster risks at a landscape level; (ii) develop coordinated and optimized responses to respond to fire related disaster risks; and (ii) exchange data, technology, and proven methods to contain forest fires. To address this gap, this review, first of its kind in the region, attempts to present an integrated review of the confluence of literature on forest fires in the Eastern Himalayan region of Nepal, Bhutan, and North Eastern Region of India, adaptation policy responses, and present policy and research recommendations for the future.

2. Methodology

2.1. Study area

The review study covered Nepal, Bhutan, and the North Eastern Region (NER) of India (NER includes the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim) of the Eastern Himalayas (Figure 1). This Eastern Himalayan landscape is a crucible of human civilization and a global biological hotspot (Wang et al. 2018). Climate and vegetation vary greatly with elevation of the landscape, from glaciers at the highest point to tropical forest at the lower elevations. The landscape rises from 300 m (tropical lowlands) to over 8,000 m

Figure 1. Study areas in the Eastern Himalayan landscape.
high mountains) in a matter of few kilometers, which has led to the evolution of highly diverse ecozones. As a result, the Eastern Himalayan landscape is endowed with a very rich habitat featuring highly diverse biodiversity with high level of endemism (Myers et al. 2000). This landscape remains a rich repository of the largest reserves of tropical and sub-tropical forests of wet evergreen, semi-evergreen, moist deciduous, coniferous forests, mixed forest, temperate, and shrubland (Roy and Joshi 2002). This biodiversity rich landscape is also a critical biological bridge or a safe haven for species migration between Eastern Asia and the Western Asia, as the areas North of the Eastern Himalayas are occupied by highly inaccessible mountains and the Southern part of the Eastern Himalayas are hugely populated and developed. Climatically, the Eastern Himalayas is dominated by monsoon from June through September during which some parts of the region gets a lot of rain. On average the region receives about 1000 mm of rainfall a year. The temperature ranges from sub-zero in the mountains to over 40°C in the plains (SFR 2009).

Majority of the household in the Eastern Himalayas are small holder agricultural farmers, who depend heavily on natural resources for water, agriculture, energy, and livelihoods. The landscape is characterized by rugged mountains and flood plains with four seasons. Winters (December to February) are dry and cold while summers (June to August) are warm and wet with monsoon rains. However, this landscape is threatened by habitat loss, wildlife poaching, human wildlife conflicts, and climate change. Forest fires further exacerbated by climate change impacts magnifies the existing threats to biodiversity, environment, and human livelihoods.

2.2. Review methods

Methodologically, we offer an interdisciplinary review of the peer-reviewed and gray literature. We used a narrative scooping review approach used by Davis et al. (2009) to narrate the present state of forest fires and resilient adaptation responses to guide the development of climate resilient adaptation pathways in the future (Figure 2). A scooping review generally uses both gray literature and peer-reviewed articles (Davis et al. 2009; Sharma et al. 2014).

Peer reviewed papers were retrieved using a systematic search in Google Scholar using different combinations of key words including: “climate change disasters, forest fires, resilience, adaptation policy/programs responses, adaptation pathways.” After obtaining an initial batch of 93 papers, we screened the articles that focused on forest fires, adaptation responses, climate change, resilience, and adaptation in the eastern Himalayas. Further we also browsed the reference lists of these papers to identify more papers that met these criterions. In addition, we reviewed gray literature including government reports, research project reports, national adaptation plans, UNFCC reports, etc. We also reviewed several global papers focusing on forest fires, climate change, and adaptation in order for us to cross compare and confirm the findings to reach a scientifically supported conclusion.

We acknowledge that this review is not comprehensive as we are biased by the authors’ selection of key words and we rely on Western search systems thus we may have excluded valuable eastern Himalayan perspectives that are often published in smaller, excluded journals. In addition, the forest fire data is not published for all areas during the same time period making national level comparisons difficult. However, in our next phase of the study, we will conduct a field survey in these countries to gather data from relevant authorities as well as carry out field observation. Nevertheless, we provide insights into common trends of forest fires, existing responses, and impact of climate change in the study area. The synthesis of the review is presented in the findings and discussions sections.
3. Findings and discussion

3.1. Extent, magnitude, and incidences of forest fires

Figures for forest fire incidences and areas burnt in the Eastern Himalayan region are presented in Table 1. Generally, on average the Eastern Himalayan region lost about 658,778.4 ha of forests a year and suffered from 3,158.5 incidences of forest fires annually (Table 1). Of the three study areas, NER of India lost maximum forest area to fire (550,086 ha) followed by Nepal (101,407.1 ha). As the smallest of the three study sites, Bhutan lost the smallest areas to forest fire annually (7285.3 ha) (Table 1). More detailed review findings are discussed below.

Bhujel et al. (2017) carried out a fire dynamics study covering a period of 17 years from 2000 to 2016 and recorded a total of 35,374 fire incidences which resulted in 1,723,920 ha of forests burnt in Nepal (Table 1). The total area burnt have steadily increased over the year from 2000 to 2016 with an average of 101,407 ha of forest burnt annually. This increasing trend is also observed at smaller scales by Kunwar (2006), whose study on forest fires in the community forest in Nepal’s Teria reported an increase in forest area burnt from 1,633 ha (14%) in 2003 to 2,854 ha (24%) in 2004. The author attributed the increase to accumulation of large amount of fuel such as dry and thick ground litter, grasses and coarse fuel particularly debris, stumps, dry branches, litters, bush and log. However, Bajracharya (2002), reported a much higher area of forest burnt annually at 400,000 ha, which is almost 3 times the area as per the data from Bhujel et al. (2017). This indicates a significant gap in the figures available for Nepal and could have been caused due to the period of study covered. A review from the NER of India showed that around 14,371 forest fire incidences have occurred between 2001 and 2014. Bahuguna and Upadhay (2002) concluded that close to 50% of all the forest fires in India take place in the NER of India. Unlike in the case of Nepal where the fire incidences steadily increased during the period of the study by (Bhujel et al. 2017), the NER of India reported a steadily increasing incidence peaking in 2006–2009 and then slowly decreasing during the period from 2001 to 2014. A total of 10,084 incidences of fires were reported in 2014 alone (Sudhakar et al. 2014), which has burnt about 550,086 ha of forest (Reddy et al. 2017) (Table 1). This decrease in fire incidences can be attributed to a more aggressive firefighting effort by the forest departments and engagement of communities in forest fire management. While total area burnt for the whole of the NER is not available in the published literature, Sudhakar et al. (2014) estimated that the two states in the NER of India, Nagaland and Mizoram have lost 20,000 ha and 26,300 ha, to fire in 2014 alone.

Figures from International Forest Fire News (Dorji 2006) shows that Bhutan reported a total of 803 forest fire incidences from 1993 to 2004 (80 fires a year), with a total burnt area of 275,642.07 ha. On average, about 80 forest fire incidences burnt about 27,564.207 ha a year. A more recent data for 6 years (2012–2017) from Bhutan’s department of forest and park services (Personal Communication 2021) revealed that 255 incidences of forest fire destroyed 43,711.7 ha of forest (Table 1). On average this works out to be about 51 fire incidences destroying an average of 7,285.3 ha of forest annually. Data from 1993 to 2004, and 2012 to 2017 show that forest fire incidences and area of forest destroyed as a result have both declined for Bhutan. This is probably due to the ban on slash and burn agriculture combined with improved fire prevention strategies such as training forest fire specialists, community members, and acquisition of better firefighting equipment that has all led to both reduction in fire out breaks as well as reducing fire damages.

Globally, fire incidences are projected to increase by about 27% by the year 2050 relative to 2000 levels (Huang et al. 2015). This finding has also been confirmed by Girardin and Mudelsee (2008) whose study predicted an increase in wildfire by about 34% by 2061 and 2100 in northwestern Ontario and eastern boreal Manitoba respectively. Westerling et al. (2006) also reported increased incidences of wildlife fires in recent decades in both Southern United States and other parts of the world. Pechony and Shindell (2010) warned that this may be a major trigger of climate change. These findings indicate that under the business-as-usual condition incidences of forest fires will continue to increase destroying large tracts of forests degrading ecosystem services, reducing biodiversity, and reducing the quality of human wellbeing. This situation begs for a deepened understanding of forest fires especially under climate change. scenarios and developing innovative interventions.

3.2. Causes and impacts of Forest fires

Forests and fires are traditionally intertwined in the eastern Himalayas due mainly to shifting cultivation or slash and burn agriculture, and the seasonal phenomenon. Based on the review from the study areas (Kunwar 2006; Sudhakar et al. 2014; Palit 2019), forest fires can be categorized as (i) natural; (ii) intentional/
deliberate; (iii) unintentional/accidental. Generally, forest fires are caused by natural (lightening, rockslide, volcanic) and human activities including slash and burn agricultural practices, deforestation, controlled burning, firewood, campfires, hunting and poaching, tea cultivation, etc. (Table 2). Intentional forest fires incidences are high accounting for almost 58% of the total causes of forest fires. This review found that most intentional fires are caused by agricultural uses. For instance, livestock owners to encourage the growth of fresh grasses for their stock. Where shifting cultivation is a way of life such as in Nepal and NER, farmers deliberately slash and burn forests to clear land for cultivation (Kunwar 2006). Sometimes, fires are also reported to be set by farmers to both encourage the growth of non-timber forest products as well as collect them. In some areas poachers set fires to clear vegetation for getting better sight of wildlife. These fires sometimes escape the farmers and cause accidental forest fires. Accidental forest fires are also caused due to negligence of people. These include smokers who intentionally throw burning butts of cigarettes and cause forest fires. This is a serious cause especially during dry months of the year in coniferous forests. Forest fires whatever the cause presents significant threat to biodiversity and humans due to limited capacity to control fires exacerbated by rugged terrain and remoteness of the eastern Himalayan landscapes. Therefore, it can be concluded that incidences of forest fire are related to increasing interference of human activities inside natural forest covers. Review findings show that agricultural related burning especially from traditional practices such as slash and burn (aka shifting cultivation and also as Jhum in northeast India) is a major cause of forest fires. A significant correlation \( r = 0.99 \) between fire incidences and shifting cultivation was reported by Sudhakar et al. (2014) in the NER of India. The study further noted that about 95% of the fires occur during shifting cultivation.

In addition to these usual causes of forest fire (Table 3), season and weather along with other physical characteristics of a landscape continue to influence forest fires. Our review showed that forest fires are most frequent during the pre-monsoon season in the Eastern Himalayas, with the highest fire incidences reported during the post dry winter months of February, March, April, and May. Bhuvel et al. (2017) and Kunwar (2006) reported that most fires occurred during the period of March to May in Nepal and that it drastically reduces by June when the monsoon season sets in. Bhuvel et al. (2017) reported that forest fires in Nepal were most frequent during the dry months of March (442 fire incidences) April (940 fire incidences) and May (239 fire incidences). This finding was seconded by Matin et al. (2017) whose study showed that 89% of the wildfires occurring during the pre-monsoon season (March to May) in Nepal. Similarly, in the NER of India, highest incidences of forest fires occurred during the month of March and April (Sudhakar et al. 2014). Similar to the findings by Bhuvel et al. (2017) for Nepal, Sharma et al. (2012) reported that higher rainfall is correlated with less fire incidences and vice versa in the state of Sikkim. Compared to Nepal and the NER of India, Bhutan’s fire season starts earlier in November and end earlier in March enduring a longer fire period (Dorji 2006). Similar to these findings, a study from South and Southwest forests of China reported a high incidence of forest fires during the months of February, March, and April (Shu and Xiaojun 2001). Giriraj et al. (2010) also observed higher incidences of wildfires in central India during March and April which is associated with long dry season. These findings confirm that while forest fires are caused by several factors, most incidences are directly associated with dry winter and spring seasons. In addition, climate change impacts such as droughts can exacerbate fires.

Forest fires impact human, natural environment, and biodiversity, as well as contribute to global warming. Studies on the impacts of forest fire (both anthropogenic and wild) on the environment and ecosystem indicated high carbon emissions (Hao and Liu 1994; Fearnside 2000), loss of biodiversity (Brown and Davis 1959), change in atmospheric chemistry, emissions of large amounts of trace gases and aerosol particles and black carbon (Dwyer et al. 1998), release of almost hundred million tons of smoke aerosols into the atmosphere (Hao and Liu 1994), and increase in surface albedo and water runoff (Darmawan et al. 2001) as a result of biomass burning. Fires not only consume or deeply char the vegetation but also affect the properties of soils, including the structure, porosity, and hydraulic conductivity (Neary et al. 1999). These impacts are felt heavily in the Eastern Himalayas as the livelihood and human wellbeing of majority of the people are closely dependent on forests and its ecosystem services. So, loss of forests significantly reduces livelihood sources thus reducing their adaptive capacities.

### 3.3. Climate change and forest fires

Climate change is increasingly becoming a major trigger of forest fires. Abnormalities in climatic conditions make forest ecosystems more susceptible to forest fires and increases the risk of burning (Sharma et al. 2012). Global warming resulting from increase in climate variability worldwide (IPCC 2007) topped with prolonged droughts and less rainfall render forests more

| Table 2. Major causes of forest fires in the eastern Himalayas. |
|---------------------------------|--------------------------------|
| **Fire category**               | **Causes of forest fires**     |
| Accidental                      | Uncontrolled burning           |
|                                 | Campfires                      |
|                                 | Roadside workers               |
| Negligence                      | Debris or charcoal burning     |
|                                 | NTFP* collectors               |
|                                 | Smokers/Passer by              |
| Deliberate                      | Agricultural burning/Shifting cultivation |
|                                 | Soil fertility                 |
|                                 | Fuel wood collectors           |
|                                 | Poachers/hunters               |
|                                 | NTFP collectors                |
|                                 | Burning for grass by grazers   |

*NTFP: Non timber forest products
prone to fires. A growing number of scientific evidences conclude that climate warming will increase the frequency and magnitude of forest fires globally (Overpeck et al. 1990; Mukhopadhyay 2009). Littell et al. (2009) have established climate change as a key driver of forest fires in the Western US, which has led to earlier and warmer springs and summers which results in increased wildfires (Westerling et al. 2006). According to Roy (2004), extended drought (due to climate warming) coupled with exploitation of timber and rapid land use changes in the Eastern Himalayas have resulted in significant increase in the frequency, size, and impact of forest fires. A recent simulation study to assess climate change effect on wildfire hazards in Bhutan by Vila-Vilardell et al. (2020) predicted a 2-fold increase in fire hazards under changing climate scenario. Sharma et al. (2012) in their remote sensing of forest fire study confirmed that long dry winters and increasing mean temperature make forests more vulnerable to fires. Overall, our review indicates that most incidences of forest fires are linked to climatic parameters such as temperature, drought, rainfall, and humidity. Increasing drought conditions, warmer climates, and less rains increases the frequency and magnitude of forest fires.

3.4. Climate resilient adaptation responses

Forest fires are as old as human civilization if not older. So, both ecosystem and humans have been continuously responding to this disaster which actually is not a bad disturbance for speciation (Parashar and Biswas 2003; Satendra and Kaushik 2014; Aponte et al. 2016). However, rapid increase in the frequency and magnitude of both natural and anthropogenic fires have exceeded our capacity to adapt to its impacts. The impacts are further magnified by the impacts of climate change especially warming effects combined with significant reduction in soil moisture content. Consequently, governments across the world have taken various initiatives to respond to forest fires especially under climate change scenarios. Policy and management responses have focused primarily on approaches that aimed at increasing the resistance to fire and restoration of burnt areas through interventions such as fire suppression and fuel management. However, these strategies have been ineffective in containing forest fires globally mainly because of their inability to reduce threats and risk in the long run (Schoennagel et al. 2017). For instance, in the Eastern Himalayan region, adaptation responses to forest fires range from traditional firefighting using tree branches to mobilizing forest staff and community members and training them on firefighting techniques and the use of more modern tools including helicopters. Community based management of forest fire have also been proven to outperform government managed forest as reported in a study by Kunwar (2006) in Nepal’s Teria landscape.

Silvicultural operations including pruning, tree thinning, and selective logging, prescribed burning, controlled grazing, and species selection to minimize fuel biomass are also practiced in the Eastern Himalayas (Table 3). In addition, reward and penalty systems are also being implemented by the governments to discourage intentional and negligence fires. Under this response, culprits responsible for causing fire are made to pay heavy penalty including prison terms (RGoB 2006). Those who report culprits are rewarded with the fines collected from the culprits. This technique although a bit old fashioned works in controlling people from deliberately causing fires.

From this review, it is evident that we need a transformational shift in policies and strategies that foster climate resilient adaptive responses/pathways to fires that provides options for people and ecosystems to adjust and reorganize to reduce future losses. Transformational change primarily involves a fundamental change in a system, its nature, and/or location that can occur in human institutions, technological and biological systems, and elsewhere (Denton et al. 2014). This shift from preserving forests based on historical baselines to adapting to evolving fires regimes must result in fire adapted communities who are climate resilient. Denton et al. (2014) has defined climate resilient pathways (CRP) as a continuing process for managing changes in climate and other driving forces affecting development, combining flexibility, innovativeness, and participative problem solving with effectiveness in mitigating and adapting to climate change. Climate resilient pathways therefore embodies a combination of current and evolving understandings of climate change consequences and conventional and alternative development pathways to meet the goals of sustainable development goals. It is an iterative process that recognize increasing atmospheric concentrations of GHGs can lead to impacts that has long term implications for sustainable development. If well-conceived climate resilient adaptive pathways can manage change within systems, where unintended consequences are
embracing climate resilient adaptive pathways involves identifying vulnerabilities to climate change impacts, assessing opportunities for reducing risks, and designing and implementing interventions that are consistent with the goals of sustainable development. These interventions can provide a blend of gradual and transformative responses that take into account a number of factors: (i) present and expected changes in both climate averages and extremes; (ii) the changing development context that affect social vulnerability, risk perception, conflict resolution, and resilience; (iii) acceptance of human agency and capacity to influence the future. To sum it up, climate resilient pathways demand decisions and interventions that consider both short and long-term horizons. According to Edenhofer et al. (2012) Climate resilient pathways have two overarching characteristics: (i) actions to mitigate and adapt to the impacts of climate change; (ii) interventions to ensure that appropriate risk management institutions, policies, and options can be identified, adopted, and maintained as an integrated part of development processes. A list of selected elements of climate resilient pathways adapted from the Denton et al. (2014) is presented in Table 4. The table categorizes climate resilient pathways into awareness, capacity, resources, and practices which can be used for developing development interventions in appropriate national, regional, and local contexts. While such climate resilient pathways provides more efficient route to achieving sustainable development goals, climate resilient pathways in forest fires must root current responses into objective interventions such as: acknowledging that fuel/biomass reduction alone cannot alter fire trends; active management of wild and prescribed fires with range of severities; and incentivize communities for effective control and management of fires. Such pathways must be constructed on the foundation of continuously evolving knowledge, with information changed in response to changing knowledge of climate parameters as well as changing social, economic, and natural resource conditions.

### 4. Conclusion

Forest fire continues to destroy large areas of forests in the Himalayas and globally, degrading ecosystem services, causing biodiversity loss, and jeopardizing livelihood sources. Forest fires also contributes to global warming mostly by releasing GHGS from burning biomass and associated deterioration of soils. These impacts are expected to worsen from increasing fire incidences partly exacerbated by climate change. Despite these challenges, forest fire management in the region is limited by lack of proper policy, capacity building, and mechanized tools. This is further complicated by very rugged terrain and hostile climatic conditions including strong winds that make fire management very difficult. This situation calls for a dynamic approach to fire management including a comprehensive policy guideline in each country. Such a guideline must be comprehensive enough to include diverse fire management interventions by a diverse group of people including the foresters, the armed forces, and the communities. Adequate financial provisions must be allocated to fire management activities and research. In particular, given the rugged terrain and poor communication facilities, community mobilization and training must be prioritized through policy that integrates modern firefighting approaches with community-based firefighting strategies. These circumstances calls for an integrated approach to forest fire management and climate resilient adaptation pathways fits the bill. Climate resilient adaptation pathways can transform current strategies and policies through a fundamental change in a system, its nature, and/or location that can occur in human institutions, technological and biological systems. However, such changes must be deeply rooted into empirical knowledge generated from robust scientific knowledge about forest fire dynamics, cause and effects under climate change scenarios. This review shows that such research are scare

| Categories                  | Attributes                                                                 |
|-----------------------------|-----------------------------------------------------------------------------|
| Awareness and capacity      | • Strong social awareness of the hazards of climate change.                 |
|                             | • Integration of national growth policies with a demonstrated ability to contribute appropriately to reducing net greenhouse gas emissions. |
|                             | • Collective actions to bring about institutional reform for more efficient resource management. |
|                             | • Leadership for long term sustainability.                                |
|                             | • Human resource growth to enhance risk management and adaptability.       |
|                             | • Access to funding for appropriate climate change adaptation plans and actions. |
|                             | • Access to scientific and technical knowledge and problem solving resources, including effective frameworks for delivering information, services, and standards. |
|                             | • Information links so that others' mitigation and adaptation experiences can be learned from. |
| Resources                   | • Monitoring of potential climate change impacts and contingency planning for responding to them, including possible needs for transformation responses. |
|                             | • Continual and review of institutionalized vulnerability assessment and risk management policy development, and refinement based on emerging knowledge and experience. |
|                             | • Policy, legislative, and legal structure that foster and entrepreneurial mindset. |

Source: adapted from Denton et al. (2014).
in the fragile Himalayan region. The review also highlights the need to understand forest fire, response mechanism, and project risks under global environmental changes in the region to carve out climate resilient adaptation pathways that will guide policy and strategies to guarantee some level of assurance to achieve sustainable development goals.

Based on the findings, this review recommends scientific studies to: (i) assess the forest fire situation in the eastern Himalayas in general and in each country in particular, that compiles the frequency of fires, area burnt, and identify the ecological, economic, and social impacts of forest fires. (ii) Evaluate the effectiveness of the current system and capacity of forest fire management at country and landscape levels. (iii) Develop and construct climate resilient adaptive indicators of forest fires including other climatic disasters such as drought, flooding, landslide, and pest and diseases. (iv) In addition, the review also point to the need for a more coordinated approach at country and community level to create awareness about forest fires and their ecological and social impacts.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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