

Assessment of climate risks on forests and biodiversity for National Adaptation Plan (NAP) formulation process in Bhutan



Assessment Report

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Acronyms

BPC:	Bhutan Power Corporation
DDM:	Department of Disaster Management
DGPC:	Druk Green Power Corporation
DHPS:	Department of Hydropower Services
DMA:	Disaster Management Act
DoFPS:	Department of Forests and Park Services
EAA:	Environmental Assessment Act
EIA:	Environmental Impact Assessment
ENSO:	El Niño-Southern Oscillation
FNCA:	Forest and Nature Conservation Act
FPED:	Forest Protection and Enforcement Division
GBCL:	Green Bhutan Corporation Limited
IFFCG:	Inter-agency Forest Fire Coordination Group
ISM:	Indian Summer Monsoon
MoAF:	Ministry of Agriculture and Forests
MoHCA:	Ministry of Home and Cultural Affairs
MTBS:	Monitoring Trends in Burn Severity
NAP:	National Adaptation Plan
NCHM:	National Center for Hydrometeorology
NEC:	National Environment Commission
NEPA:	National Environment Protection Act
NLCS:	National Land Commission Secretariat
PDO:	Pacific decadal oscillation
PPE:	Personal Protective Equipment
RBA:	Royal Bhutan Army
RBP:	Royal Bhutan Police
RCP:	Representative Concentrative Pathway
RGB:	Royal Body Guards
RGoB:	Royal Government of Bhutan
SOP:	Standard Operating Procedures
USDA:	United States Department of Agriculture
USAID:	United States Agency for International Development

Executive Summary

Forests remain central to the wellbeing and prosperity of Bhutan. From providing for water and critical environmental services, forests are inexorably tied to Bhutan's food, water, and energy security. Today, with an estimated 70% of Bhutan's total land under forests, Bhutan continues to remain carbon negative. Being in the eastern Himalayas, Bhutan's forests are also an amazing repository of biodiversity. With climate change, forests will be subjected to multiple threats ranging from novel pests and diseases to diebacks and heat related stress. Forests will also be subjected to increasing risks from forest fires. Fire related damage to forests will imperil biodiversity and severely constrain the provisioning of critical ecosystem services, and fire related loss of forests will significantly reduce Bhutan's carbon sink capacity and endanger Bhutan's ability to remain carbon neutral. Such loss will also, ultimately, compromise Bhutan's constitutional mandate to maintain 60% under forest cover for all times to come.

The objective of the current assignment is to undertake a wildfire risk assessment in Bhutan, by analyzing fire likelihood, fire behavior, and fire impact. The purpose of the assessment is to identify fire-prone areas and quantify the risks to communities, biodiversity, and assets, as well as to inform planners and managers about land management and development in fire prone areas. It will also propose prioritized adaptation options.

We used fire behaviour modelling to characterize fire hazards of Bhutan's forest ecosystems. The analysis of fire hazards, i.e., the physical characteristics of fire, is the first step towards a complete fire risk assessment, which includes fire effects on the biophysical and socioeconomic systems. We used FlamMap 5.0 (Finney et al., 2016), a spatially explicit fire behaviour model, to simulate surface fire behaviour under different representative concentration pathway (RCP) scenarios (Moss et al., 2010). FlamMap strength lies in its potential to show the effect of spatial fuel arrangement and topography on fire behaviour, as environmental conditions are held constant throughout the simulation.

To frame adaptation strategies for the next decade, we focused on highlighting results for the short time frame (now till 2050) under the RCP 4.5 scenario. Detailed results in the main text are mostly limited to projections for RCP 4.5 from now till 2050. Results for other scenarios and time slices are appended in the form of consolidated GIS maps and datasheets. We combined 'high' and 'very high' risk classes together and present results under one single high fire risk category.

Both flame length and rate of fire spread experience an increase as climate becomes more extreme (Figure 6 & 7). According to our simulations, chir pine forests experienced the most severe fire behavior, with flames reaching 2.2 m length and spread of fire at 8.9 m min^{-1} for the RCP 8.5 scenario period 2070-2100. Besides chir pine forests, the highest flame length values were found in mixed conifer forests, with flames reaching also 2.2 m length, and the fastest spread in broadleaf forests below 2000 m, with a fire line moving at 6.4 m min^{-1} . Fir forests and broadleaf forests above 2000 m underwent the mildest fire behavior outputs. This means that forest fires will be more intense with increasing possibility of more crown fires. Coupled with a faster rate of spread, the possibility of larger fires burning over longer periods is an eminent possibility.

Almost 90% of Chir pine forests fall under high risk from now till 2050 followed by blue pine with over 60% being subjected to high risk. See Figure 8 and Map 3.

Under RCP 4.5, from now till 2050, an estimated 921 km² of Chir pine, 626 km² of Blue pine, 879km² of mixed conifer forests, and 1175 km² of fir forests will be at high fire risk (Table 4). Areas under high fire risk increase significantly for mixed conifer forests for all time slices and under both RCP 4.5 and RCP 8.5. Athang and Daga Gewogs in Wangdue and Saleng Gewog in Mongar are at most risk within the Chir pine zone (Table 5) in the short time frame (now till 2050). Two Gewogs of Mewang and Kawang in Thimphu are at most risk followed by Chhoekhor Gewog in Bumtang within the Blue pine forest zone. Kazhi in Wangdue and lower reaches of Lunana Gewog show up as being at most risk followed by Langthil Gewog in Trongsa and Athang in Wangdue within the chir pine forest zone.

Risks to broadleaved forests at lower elevations (<2000) are projected to increase from now to 2050 with over 9000 km² of broadleaved forests at high fire risk under both RCP 4.5 and RCP 8.5. Pangkhar Gewog in Zhemgang and Jigmichhoeling in Sarpang followed by Trong Gewog in Trongsa and Bongo in Chapcha have the most area at risk from fires within broadleaved forests below 2000 masl.

A total of 18490 households will be at increased risk from forest fires as we move from now to 2050. Houses within the broadleaved belts below 2000 masl will be at most risk from now until 2050, followed by households within Chir pine and Blue pine zone. There are no households and infrastructure at risk within mixed conifer, fir, and broadleaved forests above 2000 masl. An estimated 1747 households will be at a high fire risk within the Chir pine zones under RCP 4.5 as we move from now till 2050. A total of 598 households will be at a high risk within the blue pine zones under RCP 4.5 as we move from now till 2050. About 14867 households will be at a high risk within the broadleaved forests below 2000 masl under RCP 4.5 as we move from now till 2050.

Of the 1774 religious structures currently recorded at the National Land Commission Secretariat, a total of 549 (30%) religious structures will be at risk under RCP 4.5 from now till 2050.

To date, despite the risks posed by the possibility of increasing forest fires, there has not been any significant investment to effectively manage forest fires. We recommend a broad suite of adaptation recommendations from now till 2050, with a focus on chir pine and blue pine forests over the next decade. Adaptation strategies will need to be simultaneously upscaled within broadleaved forests below 2000 masl. Forests at risk should be proactively managed to reduce forest fuel load. This should be supplemented by fuel clearance around key infrastructure and households at risk. Forest surrounding powerlines should also be cleared in addition to fire lines being established within forests most at risk. Importantly, forest institutions should be adequately equipped with basic firefighting equipment. These efforts should then be consolidated through strengthening mechanisms to enhance forest fire fighting response mechanisms. Given that humans are responsible for most fires in Bhutan, education and awareness building programs should be mainstreamed as part of forest fire prevention strategies. And lastly, information management and research should be strengthened to better understand, predict, prevent and manage forest fires.

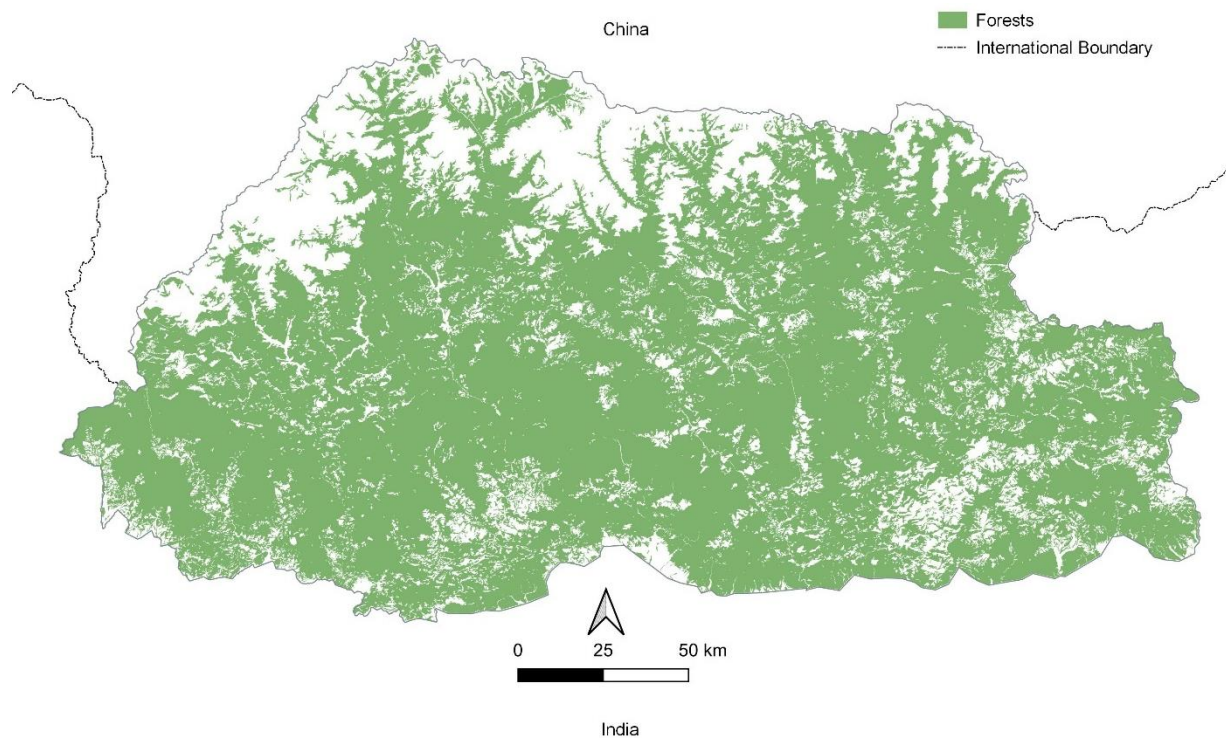
Our findings which project increasing fire risks under a warming climate align closely with unfolding fire events globally, and warn us, of what may be in store, should we fail to proactively adapt to climate change.

Failure to adapt and curtail the risks of future forest fires will entail significant economic and ecological costs for Bhutan. In addition to exacerbated loss of property and rapid disruptions to ecosystems and loss of biodiversity, increased and intensive forest fires will significantly contribute to Bhutan's carbon emissions, thereby – possibly – compromising, Bhutan's carbon neutral status. The consequences of a failure to adapt will be hugely disastrous for Bhutan.

As of now, Bhutan has made no significant long-term financial investment in forest fire management, beyond covering the cost of the DoFPS fire management staff. Given that projected risks are considerable across all forest types, it is imperative that substantive investment be secured to implement a dynamic and proactive fire mitigation and adaptation program. Such an investment will pay itself out in the form reduced carbon emissions, protected infrastructure, and conserved biodiversity.

Chapter I: Introduction

Forests remain central to the wellbeing and prosperity of Bhutan. From providing for water and critical environmental services, forests are inexorably tied to Bhutan's food, water, and energy security. Today, with an estimated 70% of Bhutan's total land under forests (See Figure 1), Bhutan continues to remain carbon negative. Recent estimates, as of 2015, show that forests sequester a total of 9421.013 Gg of CO₂e emissions (NEC 2020), far exceeding Bhutan's total GHG emissions, estimated at 3,750.563 Gg of CO₂e.



Map 1. Forest cover of Bhutan (extracted from Landuse and Landcover Map for Bhutan prepared in 2016 by the Ministry of Agriculture and Forests)

Being in the eastern Himalayas, Bhutan's forests are also an amazing repository of biodiversity. From large carnivores to birds to plants, mammals and insects, Bhutan may in fact be the last refugia for biodiversity in the eastern Himalayas (Tempa et al 2013). Furthermore, Bhutan's six agrobiodiversity zones host a wide variety of crop and livestock biodiversity.

Alongside storing biodiversity, forests provision for food, water, and energy, and stem the loss of soil and prevent land degradation (Sears et al 2018). With climate change, forests will be subjected to multiple threats ranging from novel pests and diseases to diebacks and heat related stress. Consequentially, forests will be subjected to increasing risks from forest fires (Vilà-Vilardell, L. *et al.* 2020).

As climate continues to warm, increasing fire related damages will severely reduce the provisioning of critical ecosystem services and fire related forest loss will significantly reduce Bhutan's carbon sink capacity and imperil Bhutan's ability to remain carbon neutral. Such loss will also, ultimately, compromise Bhutan's constitutional mandate to maintain 60% under forest cover for all times to come. Worryingly, fires and fire related destruction are increasing worldwide with damaging consequences on lives, ecology and economic health.

As a matter of critical concern, across the globe, many recent fires have burned ecosystems where fire has historically been rare or absent including the tropical broadleaved forests of southeast Asia and South America (Kelly et al 2019). Tropical broadleaf forests of the Afrotropical, Indomalayan, and Neotropical realms rarely experienced large fires until recently. These changes pose significant challenge for understanding how to sustain biodiversity and protect homes and infrastructure in a new era of large catastrophic fires. It also behooves us to improve knowledge and understanding of the linkages between fire, biodiversity and humans.

Fire regime, a key concept within fire science, describes the type, frequency, intensity, seasonality and spatial dimensions of recurrent fire. Fire regimes determine biodiversity and biodiversity in turn influences fire regime. For instance, plants that require fire to release seeds can be threatened by fire intervals shorter than the time needed for plants to mature and re-establish a seed bank. For animals, changes in the frequency and intensity of fire can reduce foraging and sheltering resources and increase mortality. Abrupt changes in fire regime hold significant consequence for biodiversity persistence.

In Bhutan, as of now, there is limited understanding of the extent to which fires negatively impact forests, associated biodiversity, human property and infrastructure. Furthermore, an appreciation of the extent to which fire risks will escalate into the future under a warming climate is wanting. This lack of understanding hampers the design and implementation of fire related adaptation and mitigation responses.

Given the rampant spread and high frequency of forest fires across the globe – even in previously unburnt ecosystems – it is critical that risks and vulnerabilities to forests from fires be quantified and fire prone areas be identified. Such an assessment will ensure quantification of risks to communities, biodiversity, and assets, and help inform planners and managers about land management and development in fire prone areas.

Chapter II: Objectives of the Assessment & Structure of the Report

The objective of the current assignment is to undertake a wildfire risk assessment in Bhutan, by analyzing fire likelihood, fire behavior, and fire impact. The purpose of the assessment is to identify fire-prone areas and quantify the risks to communities, biodiversity, and assets, as well as to inform planners and managers about land management and development in fire prone areas. It also proposes prioritized adaptation options.

Chapter I provides a brief introduction on the importance of Bhutan's forests and the need to understand fire risks and impacts under a changing climate.

Chapter II provides a review of the nexus between climate, vegetation, fire, and human interactions.

Chapter III provides the objectives of the assignment.

Chapter IV describes the methods used in the study and discusses its limitations.

Chapter V presents the results from the models and spatial risk analyses and highlights risk zones under RCP 4.5 and RCP 8.5 across three-time scales: near (2021 – 2050); mid (2051 – 2070); and long (2071 – 2100).

Chapter VI prescribes adaptation priorities.

Chapter VII concludes the report by highlighting the need to focus efforts on managing forest fuels and improving response systems.

Chapter III: Context Setting – Fires in a Changing World

Emissions from industrial processes, agricultural burning and wildfires are increasing the concentrations of radiatively active gases in the atmosphere, i.e., greenhouse gasses (GHG). Chief among these is carbon dioxide, but water vapor, ozone, methane, nitrous oxide, and various chlorocarbons are also important. Changes in radiative properties, are expected to affect global circulation patterns, significantly altering regional climate (Pattnayak et al. 2017, Fill et al. 2019, Almazroui et al. 2020). The effects on climate are expected to significantly impact Southeast Asia, particularly the Himalayan countries (Dorji et al. 2016, Lamsal et al. 2018).

Climate, the integration of precipitation, temperature and wind has long been recognized as a dominant factor controlling the distribution of vegetation across latitude, elevation, and aspect (Woodward 1987, Ohsawa 2009). Climate is generally defined as the average weather for the previous thirty years. While climate is a major driver of vegetation development that determines the physiognomy and chemistry of the vegetation, short term weather dominates fire potential. Throughout evolution vegetation has developed in response to changes in atmospheric chemistry and climate as well as episodic events including floods, avalanches, extreme weather, and fire (Bond and Keeley 2005, Keeley et al. 2011, McLauchlan et al. 2020). The climate-vegetation-fire dynamic has always been in flux throughout space and time (Ryan and Koerner 2012). Changes in any one element can be expected to have concatenating effects on the other two, and thus feedbacks (Ryan 1991, Ryan and Opperman 2013) (figure 1).

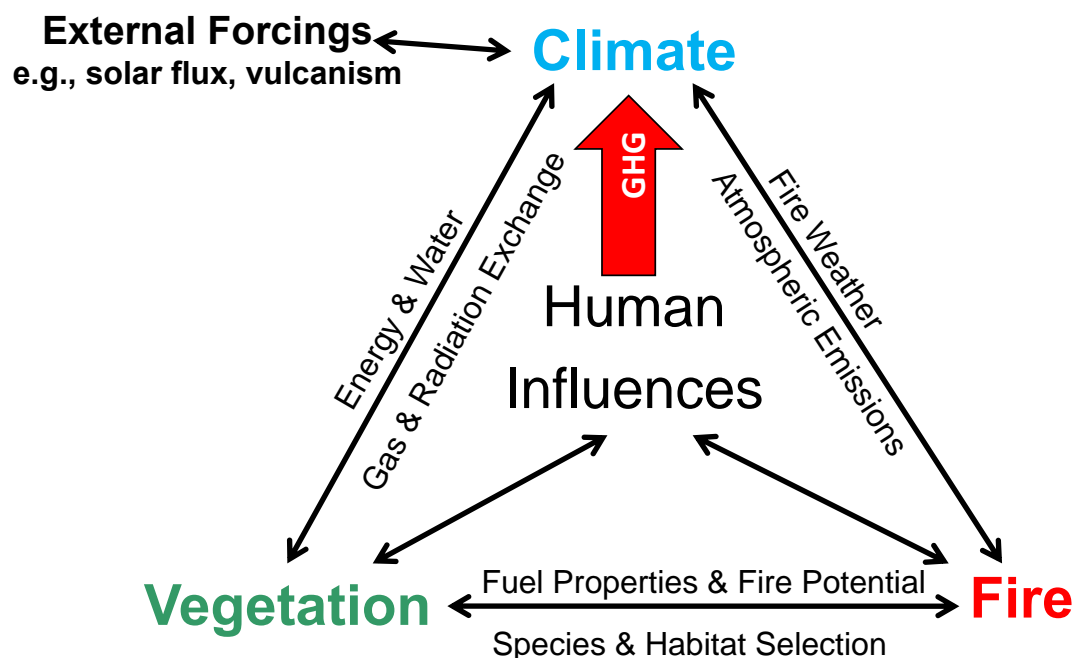


Figure 1. Climate is dynamically coupled to vegetation, fire, human activities and external forcings (adapted from Ryan et al. 2012).

Figure 1 illustrates these dynamic interactions and humanity's role in changing the face of the earth. Policy makers and managers need to recognize climate, vegetation and fire are dynamically coupled, and historically deeply linked to human culture (Bond and Keeley 2005; Bowman et al. 2011, 2013; Scott et al. 2015). All aspects of human endeavor can be expected to be affected to some degree.

1.1 Climate and Vegetation

Biophysically, vegetative productivity is determined by the available water, energy, and nutrients. Water and energy budgets are affected by latitude, elevation, aspect, slope steepness, and cloud cover. Precipitation and temperature are recognized as the dominant factors affecting the potential vegetation that could grow on a site in the absence of disturbance (LaPiere et al. 2016, Mishra and Maimali 2017, Pareek 2017, Gwal et al. 2020). These also directly impact soil development, which is a critical element of site productivity via a soil's water and nutrient holding capacities. Latitude and proximity to oceans result in macroclimates with relatively reliable temperature and precipitation regimes. Macroclimates experience episodic shifts linked to ocean-atmosphere circulation patterns, (e.g., ENSO, PDO, IOD). Macroclimates are recognized as important elements in vegetation zonation. Warming climate is expected to shift vegetation zones farther from the equator, and up in elevation. This is critical at regional to continental scales (Davies-Barnard et al. 2015).

At sub-regional and landscape scales terrain exerts increasing influence on site productivity (Gwal et al. 2020). Given the adiabatic lapse rate in the atmosphere and the influence of terrain on orographic precipitation, or conversely a rain shadow, elevation has a major effect on mesoclimate. Aspect and slope also affect the energy and water budgets via their influence on solar insolation and water retention, respectively. Likewise, cloud cover has a major influence on water and energy budgets (Scholl et al. 2011). The combined effects of terrain: slope, aspect and elevation, and cloud cover cause vegetation zones to shift in mountainous areas. Terrain complexity therefore has a dominant effect on the species composition, density, physiognomy, and spatial distribution of vegetation. Vegetation zones are expected to migrate to higher elevations under warming climate (Sidgel et al. 2018, Mainali et al. 2020), but existent zones may be extirpated from some mountain ranges leading to habitat fragmentation.

By the end of this century Bhutan is projected to warm by 0.8° C to 2.8° C under the RCP 4.5 scenario and by 0.8° C to more than 3.2° C under the 8.5 scenario. Precipitation is expected to increase by as much 30 percent with wet-season (JJAS) precipitation increasing by 5 to 15 percent (Das et al. 2016, Dorji and Tamang 2019). These changes will affect eco-physiological processes and competitive status of plants and animals, differentially by species and age. Climate change alone can be expected to affect vegetation zonation and the species composition of future plant communities and faunal habitats. Warming can be expected to raise elevation zones. Because species have physiological optimums/tolerances to temperature, precipitation and atmospheric chemistry, inter-specific competitive relationships will change in uncertain ways. Because species have life-cycle attributes that affect their mobility, not all species will be able to migrate to emerging niches. Present-day communities can be expected to disaggregate, and new community associations emerge. Limited knowledge of species physiological requirements and competitive relationships create challenges for future biodiversity projections.

1.2 Vegetation and Fire

Living and dead vegetation constitute the fuel essential for combustion (Scott and Burgan 2005, Pickering et al. 2020). Conceptually, the wildfire potential of an area can be viewed as a function of site productivity and the cumulative frequency of moisture deficit. The amount of fuel on a specific site varies with the ratio of productivity to decomposition and with the history of past disturbance and land use. For example, herbivory, particularly by domestic animals removes fine fuels thereby reducing potential for fire to spread. Conversely, storm damage, avalanches, insect outbreaks and logging often create temporary spikes in fuel volume and increased fire potential (Cawson et al. 2018, McColl-Gausden and Penman 2019, Leverkus et al. 2020).

Fire is a major ecosystem process in many of the world's ecosystems (Bond and Keeley 2005; Keeley et al. 2011; He et al. 2012, 2019; Scott et al. 2015). Vegetation and fire integrate across multiple spatial and temporal scales (Ryan and Koerner 2012). Fire has immediate impacts to individual organisms upon exposure to heat and longer-term impacts to organisms' habitats at plot, stand and landscape scales. The behavior (Werth et al. 2016) and effects (Ryan 2002, Lutes and Keane 2017) of a fire are determined by the legacy conditions, actual (real-time) fire weather and suppression activities (Kaufmann et al. 2009) (figure 2). The impact of the fire on the biota, infrastructure, ecosystem services and the like, are also influenced by post fire events (e.g., precipitation, insects, disease, erosion, etc.) acting upon the fire-altered environment (Certini 2013; Iyas and Khan 2005; Neary et al. 2005; Cerda and Robichaud 2009; Ryan and Koerner 2012; Hood and Lutes 2017; Pyke 2017; Hood et al. 2018; Day et al. 2020; Simpson et al. 2020).

Fire regimes emerge over time in response to composition and physiognomy of the vegetation, and the prevalence of ignition sources. An ecosystem's fire regime is characterized by its frequency or fire return interval, the seasonal timing of fire occurrence, typical fire size, fire intensity, and burn severity (aka fire severity). Fire type, i.e., ground fire, surface fire, or crown fire, is also used in fire regime descriptions (McLauchlan et al. 2020). Uniform cycles, implied in the spirals in Figure 2, lead to stable repeatable vegetation-fire response patterns. Changes in climate drivers, land use practices and exotic/invasive species introductions alter vegetation-climate patterns sending sites and ecosystems on new evolutionary trajectories with uncertain futures (Day et al. 2020, Konsam et al. 2020).

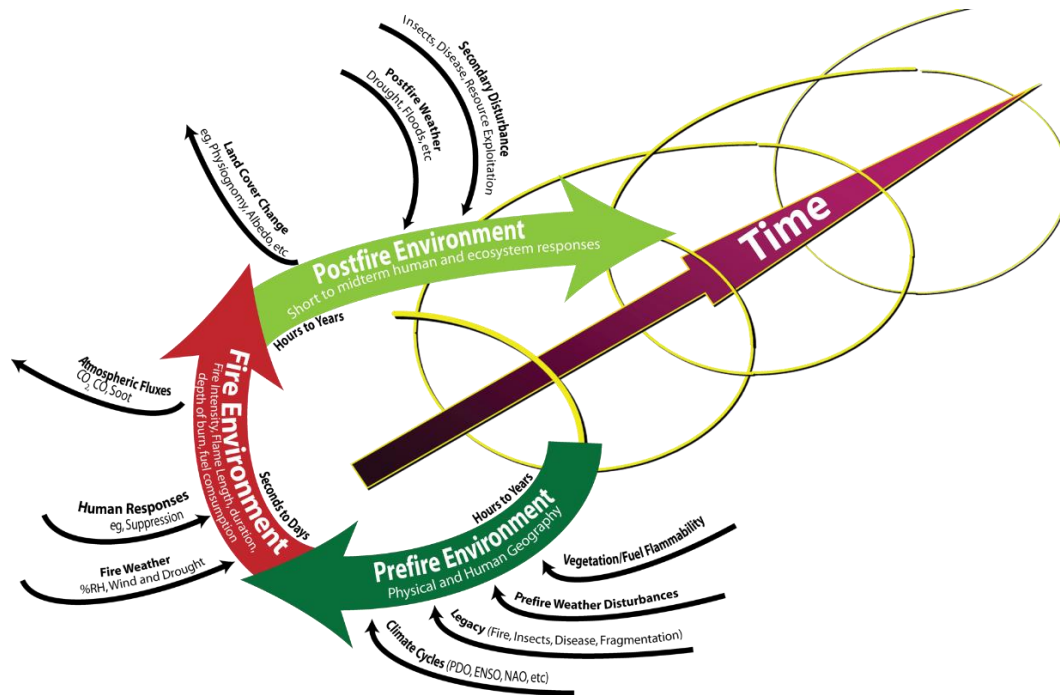


Figure 2. Fire behavior and the direct effects of fire are driven by the prevailing conditions, fuels and weather. Departures/changes in the mean fire return interval (spirals) affects all aspects of the ecosystem and resultant ecosystem services (adapted from Kauffmann et al. 2009)

Vegetation types are broad descriptions that are applied in numerous ecological and management contexts. In the context of fire, living and dead vegetation constitute the fuel that is combusted (Cochrane and Ryan 2009, Goldammer 2017). Fires rarely consume all of a site's biomass above the mineral soil interface. Significant combustion of organic matter within the mineral soil is minimal in all but the most severe fires (Ryan 2002, Neary et al. 2005, Keeley 2009). The total fuel is the fuel that can burn in a worst-case fire. For example, sound tree stems remain after intense crown fires. The available fuel is that portion of the biomass that can actually burn in a given fire and are thus not included in total fuel calculations. The science of fire behavior prediction is the science of determining the available fuel and the rate at which its energy will be released by combustion (Rothermel 1972, Finney 2004). The chemical composition of the vegetation and how its mass and particle size distribution are configured in three-dimensional space dictate whether and how vegetation burns. Vegetative physiognomy (e.g., grass, shrub, tree) are general descriptions for conveying information about the types of wildland fuels present. A more specific term "fuel bed" describes the kinds of fuels that are likely to burn (Figure 3). Fuel models are stylized descriptions of fuel bed characteristics that define input variables for computation of fire behavior (Scott and Burgan 2005) or effects (Reinhardt et al. 1997, Lutes and Keane 2017). While there is some guidance for parsing mensurational data from forest inventories or ecological surveys into fuel bed components, it requires seasoned judgement and calibration via expert opinion of fire specialists with local experience (Prichard et al. 2019). Such are in the early stages of development in Bhutan (Vilà-Vilardell et al. 2020).

Fuel beds are commonly divided into strata (Figure 3): ground fuels (mosses, lichens and detritus in contact with the soil, e.g., litter and duff), surface fuels (grasses, forbs, shrubs and saplings nominally < 2 meters high), and aerial fuels (tall shrubs, trees and epiphytes > 2meters high).







Stratum		Category	Combustion type
Canopy		Trees, snags, and ladder fuels	Crown fire
Shrubs		Primary and secondary layers	
Nonwoody vegetation		Primary and secondary layers	Surface fire
Woody fuels		All wood, sound wood, rotten wood, stumps, and woody fuel accumulations	
Litter-lichen-moss		Litter, lichen, and moss layers	Smoldering, residual effects
Ground fuels		Duff, basal accumulations, and squirrel middens	

Figure 3. Fuel bed strata and components (Ottmar 2015)

However, these are historic conventions. The spatial continuity of fuel beds in three-dimensions is poorly understood and an area of active research (Linn et al. 2002; Parsons et al. 2011, 2017). Fuel bed properties are critical to fire potential. Wetting, drying, and burning rates depend on fuel elements' particle size distribution (surface area to volume ratio) and spatial arrangement (fuel bed bulk density). Traditionally fuels have been parsed into size classes for field measurements and fire modeling (Rothermel 1972, Scott and Burgan 2005, Wotton et al. 2009) based on the fuel equilibrium moisture (M_{ce}) time-lag principle (e.g., 1-hr, 10-hr, 100-hr, & 1,000-hr) roughly corresponding to (0 - 0.6 cm, 0.7 - 2.5 cm, 2.6 - 7.5 cm, and 7.6 - 23.0 cm diameter). This is based on the observation that non-humified fuels are nominally cylindrical. The 1- and 10-hour fuels are primarily responsible for a fire's rate of spread and intensity. Mosses and lichens respond to changes in relative humidity on second to minute time scales. Mosses, lichens, 1-hour, and 10-hour fuels are collectively referred to as fine fuels. These respond rapidly to changes in relative humidity resulting in diurnal changes in fire behavior. The 100-hour and 1,000-hour fuels are collectively referred to as coarse woody debris (CWD) (Keane et al 2013). One-hundred hour and longer-drying fuels play a lessor role in fire behavior but an increasingly important role in determining fire effects (Albini and Reinhardt 1995, Ryan 2002, Neary et al. 2005, Keeley 2009, Cerda and Robichaud 2009, Ryan and Koerner 2012). The dynamic coupling between near-surface organic soil horizons, the capillary fringe and water table (hydroperiod) fluctuations brings into play physics beyond the scope of time-lag-equilibrium moisture content principles. Thus, drought codes, e.g., Palmer Drought Index, better represent moisture relations of these fuels (Wotton et al 2009, Riley et al. 2013).

Fire potential depends not only on the fuel bed properties but also weather and terrain. The energy content of fuel bed biomass varies modestly (Rothermel 1972). The most critical chemical property is the moisture content which varies seasonally (wet season vs. dry season), diurnally, and episodically with ocean-atmosphere circulation (e.g., ENSO, PDO, ISM, etc.) (Myers et al. 2015, Kathayat et al. 2018, Gupta et al. 2020).

In general, the total amount of fuel increases from a grassland to shrubland to forest (Figure 3). However, subtropical grasslands are more productive than semi-arid shrublands, for example. So, variations in fuel volumes are strongly tied to the site's specific climate and the site's inherent productivity. Productive forest sites exposed to frequent fire support available fuels in grasses and shrubs that can burn during most dry seasons leading to altered fire regimes (Goldammer 2017). Grassland fuels are fully exposed to sunlight and wind. As a result, they are frequently in a burnable condition. When grass fuels are plentiful and continuous rapid rates of spread are possible, particularly on steep slopes and with brisk winds. However, because the mass of fuel is quickly consumed most of the fire's energy is transferred to the atmosphere and little soil heating occurs (Ryan 2002). Shrublands are fully exposed to sun and wind and often exhibit extreme fire behavior at higher stand densities. However, shrubs beneath forest canopies are sheltered from sun and wind. Thus, favorable burning conditions occur less frequently. When conditions are favorable these fuels play an important role in the transition from surface fire to crown fires as so called "ladder fuels." Transitions from surface fire to crown fire in coniferous forests result in rapid spread rates, high intensity and long-range broadcasting of burning embers (spotting) (Albini 1976, Finney 2004, Wotton et al. 2009).

With forest densification primary production shifts to shrub and canopy foliage thereby reducing fine fuels near the surface. Species composition increasingly shifts to shade-tolerant species, fuel wetting and drying cycles shift to longer time frames, and within-canopy wind speed decreases. The modified fuels and microclimate translate into reduced potential for fires to burn extending fire free periods (Cawson et al. 2018, Pickering et al. 2020). However, during drought periods closed evergreen forests exhibit extreme fire behavior and severity resulting in maximum damage to infrastructure and site degradation (Certini 2013; Werth et al. 2011; Lecina-Diaz et al. 2014). Cool-moist forests (e.g., *Abies*, *Picea* and *Tsuga*) typically only burn under late dry season, extreme drought conditions. "Hold-over" fires smoldering in deep duff and rotten logs are then common and present considerable obstacle to fire control. Extreme drought is not, however, a requisite for fire in such forests. They can burn intensely under low humidity and high wind. Such events are infrequent, tend to be of short duration, but are highly lethal to overstory trees (Ryan 2002).

Vegetation and fire dynamics exist at multiple scales. Over evolutionary time scales plants and animals have developed multiple adaptations to fire (Keeley et al. 2011, He et al. 2012). These include thick bark, bud scales, epicormic buds and leaf sheaths that insulate meristematic tissue; sprouting from basal or underground structures (e.g., rhizomes, corms, lignotubers, bulbs); and fire-stimulated flowering and seed dispersal) (He et al. 2012; Pausas and Keeley 2014, Pyke 2017, USDA 2021). Some species store seeds in the soil for long periods and sprout only after fire (Konsam et al. 2020, Keeley and Pausas 2018).

Although fire has been a major ecosystem process throughout recent geological time, some regions show relatively few fire adaptations indicating that natural ignition sources, lightning and vulcanism, were rare (Bowman et al. 2009, Taylor 2010, Goldammer 2017). Such ecosystems are fuel limited either because

biomass production is quite low or ample biomass is present but is rarely dry enough to burn. The modern presence of fire in these ecosystems are directly attributable to human land use (Gupta et al. 2009, Hunt et al. 2014, Dorji et al. 2016, Jha et al. 2021). In contrast, some regions have numerous natural fire-adapted species associated with identifiable fire regimes. In some areas lightning is common, but fires are limited by the time necessary to produce sufficient biomass to carry a fire and human ignitions initiate little additional vegetative change. In contrast, subtropical ecosystems throughout the world experience frequent lightning fire (Goldammer 2017). In yet other cases ecosystems have been heavily altered by human activity such that a small number of native species and numerous exotic fire-adapted species have come to dominate the vegetation resulting in human-dominated ecosystems with permanently altered fire regimes. Given the history of land use, steep environmental gradients, diverse microclimates of the Himalayan Mountains, all such conditions are likely to occur over short distances.

Given the long evolutionary history of vegetation development with fire even long-unburned forests have species capable of rapidly responding following fire. Fire behavior ebbs and flows with changes in fuels, weather, and terrain (Ryan 2002, Goldammer 2017). Changes in plant community are commonly accompanied by transition zones where more moderate fire behavior selectively kills susceptible vegetation that subsequently become fuel for the next fire. The modified fuels and microenvironment predispose the new community to another fire. If ignitions are present all elements for a fire regime shift are present. The extent to which climate change increases the frequency and duration of favorable burning conditions will dictate the floral and faunal responses to human and lightning ignitions.

1.3 Climate and Fire

Mesoclimate has an overarching influence on vegetation development. Mesoclimates describe in a general way the type of fire weather to expect in a region (c.f., Ryan et al. 2013). Fire Climate Zones indicate the overarching potential of a region to support fire, and thus reflect the relative level of fire business to be expected. Given the absence of vegetation in alpine/glaciated areas, Bhutan appears to have three distinct fire climate zones: subtropical foothills, temperate montane, and high montane-subalpine. These zones can be expected to migrate upwards in response to climate change (Chettri et al. 2018, Mainali et al. 2020).

Although precipitation is generally expected to increase in Bhutan (Das et al. 2016, Doji and Tamang 2019) increases are expected to be less from east to west. Total precipitation is not, however, as critical as the intra- and inter-annual patterns of precipitation. Climate change is expected to increase the frequency of severe storms and lightning (Romps et al. 2014, Veraverbeke et al. 2017). Lightning patterns are, however, uncertain and will likely vary with latitude and terrain (Finney et al. 2018). Increased lightning may result in increased ignitions if fuel beds are dry and receptive. The two highest lightning zones in the United States are the southeast and southwest. In these areas “dry lightning” is common in advance of the Gulf of Mexico and Baja monsoon seasons, respectively. Both regions have high natural fire frequencies and numerable fire-adapted plants. Fires are particularly troublesome in number, duration and severity in drought years. Similar pre-monsoonal patterns occur in Central and South America, Africa, and southern Asia (Goldammer 2017). If lightning precedes wetting monsoon rains, fires in rugged, inaccessible terrain could emerge as major disturbances affecting biodiversity and ecosystem services.

Microclimate near the surface $\sim < 1$ meter is critical for fire initiation and propagation. The most critical meteorological variable affecting fuel moisture is relative humidity (RH). RH directly affects fuel moisture via the time-lag/equilibrium moisture content (Mc_e) relationship. Mc_e is little affected by atmospheric temperature *per se*. However, the intensity of solar radiation does affect fuel temperature at the boundary layer and therefore the ease of ignition. Thus, cloud cover affects fire initiation. Temperature also affects the ease with which lethal temperatures can be reached and, therefore, has a minor effect on fire survival. Wind near the surface is a critical element of fire behavior (Rothermel 1972; Wotton et al. 2009, Werth et al. 2016). Wind speed decreases with increasing forest canopy density.

Wildland fire science and management has a longstanding tradition of defining fire potential as a function of fuels, weather and terrain, i.e., the “fire environment” concept. As previously noted, fuels are a property of the vegetative community (total fuel) and drying trends (available fuel). RH and wind speed are critical drivers of fire behavior (Rothermel 1972; Scott and Burgan 2005, Wotton et al. 2009; Werth *et al* 2016). Terrain (slope, aspect and elevation) affects diurnal temperature, RH, and wind profiles. Slope steepness is a major contributor to a fire’s rate of spread. Terrain exerts another influence of critical importance in mountainous regions. In flat or gently-undulating terrain microclimate is more uniform and similar to the mesoclimate. As a result, the entire landscape either is in a burnable or non-burnable condition. Fires tend to be larger on flat terrain. In contrast, in complex terrain, total and available fuel vary over short distances. Warmer exposures are frequently dry enough to burn at least a few hours each day during the dry season. Cooler exposures are infrequently dry enough to burn, and then usually only after extended drying. Fires tend to be smaller in complex terrain, but more difficult to control.

Seasonal drying trends and episodic drought increase the amount of fuel available to burn thereby enhancing real-time fire behavior, increasing the complexity and difficulty of fire suppression and increasing burn severity (Ryan 2002). Delays in the onset of the rainy season or early snow melt potentially lead to extended fire seasons depending on daily drying trends (e.g., RH, fog-drip, and cloud cover). Changes in ocean/atmospheric circulation affect drought cycles. If shifts in the mesoclimate are associated with longer and dryer fire seasons and more frequent droughts, fire regimes will be altered. The increased frequency and severity of fire will impact humans, ecosystem services, and biodiversity. Significant increases in fire can be expected to directly affect biodiversity via habitat destruction and fragmentation. Recently burned landscapes are susceptible to erosion (Cerdeira and Robichaud 2009). If the frequency and extent of burning increases significantly major disruptions in the timing, flow and quality of water can be expected (Tariq et al. 2021). Given the importance of relative humidity and wind to fire spread and the lack of spatial- and temporal-scale resolution in climate prediction models, policy and management needs to focus on strategic vegetation management and increased fire management capabilities.

1.4 Human Interactions with Fire

The observable patterns of human’s historical use of fire to promote grazing and agriculture inform our understanding of ancient practices (Casillo et al. 2016, Jha et al. 2021). Roughly 40,000 years ago a new hunter-gatherer/fire-starter emerged on the southern Asia landscape (Miao et al. 2020, Jha et al. 2021). Hunters used fire to drive, attract, and expose game. Gatherers used fire to promote favored plants and improve habitat. As societies developed, traditional ecological knowledge expanded (Jha et al. 2021). Fire was used to improve forage production, clear and fertilize land, manage predators and pests, and provide

defensible space. There is evidence of continuous, increasing burning, deforestation and agricultural land uses over the last 2,000 years in south-eastern Bhutan (Miyamoto et al. 2012).

The behavior and effects of fire are of concern to policy makers and managers because of their social-economic consequences (DeFries and Nagendra 2017). Preparation to manage wildfires, or use prescribed fire, is reliant on an understanding of fire behavior, fire effects and risks. All are essential inputs to strategic and tactical planning. Sound risk management requires knowledge of both the values at risk and the potential for fire to harm those values (Calkin et al. 2011; Thompson et al. 2011, Dunn et al. 2021). Fire behavior describes the spread and intensity of a fire and thus the degree of difficulty for suppression. Fire effects are often of greater concern due to the potential long-term impacts on ecosystem services and biodiversity (Kelly et al 2021).

Fire behavior and effects are dictated by the prevailing conditions at the time of fire (Figure 2). Fire chemically alters residual biomass including the release of gases, aerosols, and particulate matter to the atmosphere, and it releases energy. Fire effects occur at both spatial and temporal scales. Some effects are instantaneous while others occur over time. Spatial scales vary from the micro-scale to landscape scale. Fire effects are often considered direct or indirect. As spatial and temporal scales increase, it is increasingly difficult to ascribe an observed change as a direct effect. Fire has few direct effects: it consumes biomass thereby releasing energy and minerals. Over 100 chemical compounds have been identified in wildland fire smoke (Jayarathne et al. 2018). The energy released is dynamically coupled to the atmosphere in the short term, pyro-cumulous clouds being an extreme example (Werth et al 2016).

The energy released also works to change physical and biotic site factors, killing plant and animal tissue, for example (Hood *et al.* 2018). The terms “fire severity” and “burn severity” are commonly used to describe the suite of changes directly affected by fire (Ryan 2002). The primary attributes of burn severity are the amount of biomass consumed and the amount of the biota killed. A plant may be top-killed (direct) yet survive via sprouting from below-ground meristems (indirect). The soil surface might be denuded by fire (direct) then eroded by rain or wind (indirect). Distinctions between direct and indirect effects has little relevance in policy discussions and management activities. However, such distinctions do come into play when designing prescriptions for using fire to manage vegetation, developing post fire rehabilitation actions, and in developing monitoring frameworks to support adaptive management.

Chapter IV: Modelling Forest Fire Risks & Implications in Bhutan from A Changing Climate

4.1 Assessing Current Situation

We compiled fire occurrence data available from the Department of Forests and Park Services (DoFPS) of the Ministry of Agriculture and Forests (MoAF). We tabulated area burnt statistics by location and forest type and created a heatmap in QGIS to visually appreciate the spatial distribution and extent of extant forest fire patterns.

4.2 Predicting Future Fires Scenarios Using FlamMap

We used fire behaviour modelling to characterize fire hazards of Bhutan's forest ecosystems. The analysis of fire hazards, i.e., the physical characteristics of fire, is the first step towards a complete fire risk assessment, which includes fire effects on the biophysical and socioeconomic systems. We used FlamMap 5.0 (Finney et al., 2016), a spatially explicit fire behaviour model, to simulate surface fire behaviour under different representative concentration pathway (RCP) scenarios (Moss et al., 2010). FlamMap strength lies in its potential to show the effect of spatial fuel arrangement and topography on fire behaviour, as environmental conditions are held constant throughout the simulation. The model calculates fire behaviour on each pixel independently, by assuming that every pixel from the landscape burns (Finney, 2006). As fire behaviour indicators we used flame length (m) and rate of fire spread (m min^{-1}). Simulations were done in 30 x 30 m pixels.

FlamMap input parameters are grouped into three blocks: topography data, fuel data, and weather data. *Topography data* (elevation, slope, and aspect) are input as raster layers. Topography was derived from a Digital Elevation Model at 30-meter resolution.

Fuel data include canopy fuels and surface fuels. Forest ecosystems of Bhutan were classified according to the land use land cover categories of DoFPS (2016a) and expert criteria: broadleaf forests below 2000 m, broadleaf forests above 2000 m, chir pine forests, blue pine forests, mixed conifer forests, and fir forests. In FlamMap, *canopy fuels* (canopy cover, stand height, and canopy base height) are used to estimate the amount of radiation and wind reaching surface fuels and the probability of torching. We estimated canopy fuel parameters from previous studies done in Bhutan (Vilà-Vilardell et al., 2020, DoFPS, 2017, Gratzner et al., 2004, Gratzner and Rai 2003) and data of the National Forest Inventory (DoFPS, 2016b) (Table 1). . FlamMap uses canopy bulk density to calculate spread of a crown fire. In this study we focused on surface fire rate of spread and flame length, therefore canopy bulk density was set constant at 0.2 kg m^{-3}

Table 1. Canopy fuel parameters set as input for each forest type.

	Blue pine	Broadleaf	Chir pine	Fir	Mixed conifer
Stand height (m)	16.9	13.9	12.2	13.5	14.1
Canopy base height (m)	6.9	4.6	4.4	4.5	4.7
Canopy cover (%)	67	60	30	61	50

Surface fire spread is characterized through fire behaviour fuel models, which are a set of *surface fuel* parameters that define the main carrier of fire and are used for Rothermel's mathematical fire spread model (Rothermel, 1972). A fuel model includes live and dead fuel load, fuel bed depth, surface-area-to-volume ratio, moisture of extinction, and heat content.

Prior to simulation, we analyzed the fire behavior sensitivity of each forest type to different fuel models in order to (i) choose the most appropriate fuel model which resembles the behavior of a fire in that forest and (ii) take into account an increase in fuel load and change of fuel composition due to climate change (Figure 4). In other words, the fuel model which better mimicked the behavior of a fire in each forest was assigned to RCP 4.5 time slices 2021-2050 and 2051-2069, and to RCP 8.5 time slice 2021-2050. We considered that under these scenarios forest structure and composition would not change significantly nor would the behavior of a fire. In contrast, the rest of time slices for both RCP scenarios were assigned a fuel model which better represented the future composition of the forest given an increase in CO₂ into the atmosphere. Main fire carrier of fuel models of the family TL is litter and dead woody fuels, main fire carrier of the family TU is forest litter with herbaceous or shrub fuels (Scott and Burgan, 2005). Fuel models used are those described in Scott and Burgan (2005). Based on expert opinion, the final set of fuel models used is shown in Table 2.

Figure 4. Outputs of the fuel models tested per forest type.

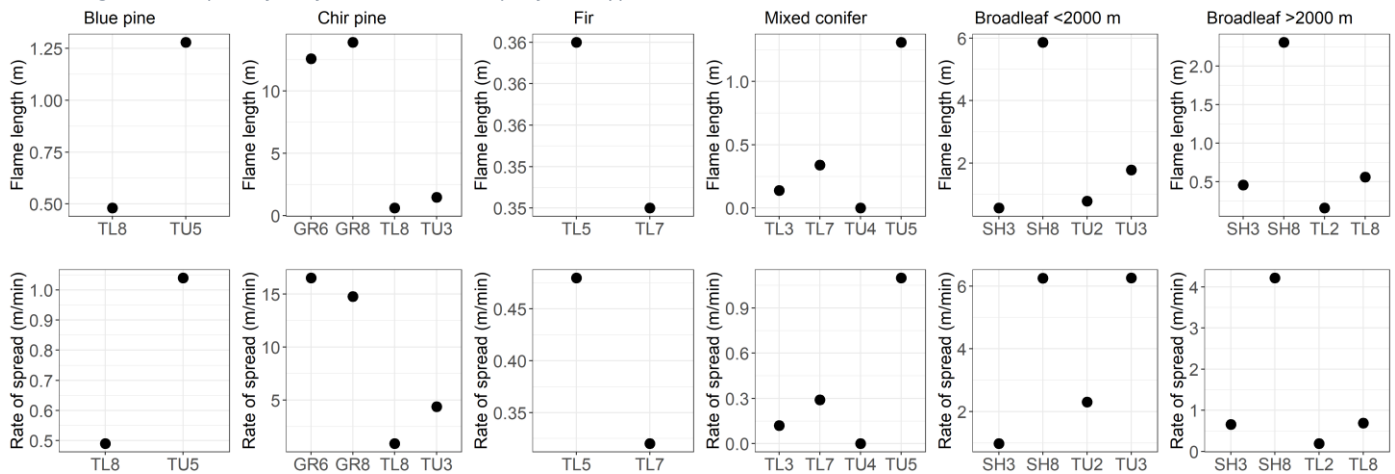


Table 2. Fuel models used to model fire behaviour for each forest type and climate scenario.

Time Slice	Period	Blue pine	Broadleaf <2000 masl	Broadleaf >2000 masl	Chir pine	Fir	Mixed Conifer
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RCP 4.5	2021 – 2050	Short	TL8	TU2	TL2	TL8	TL7	TL3
	2051 – 2069	Mid	TL8	TU2	TL2	TL8	TL7	TL3
	2070 – 2099	Long	TU5	TU3	TL8	TU3	TL5	TU5
RCP 8.5	2021 – 2050	Short	TL8	TU2	TL2	TL8	TL7	TL3
	2051 – 2069	Mid	TU5	TU3	TL8	TU3	TL5	TU5
	2070 – 2099	Long	TU5	TU3	TL8	TU3	TL5	TU5

Besides fuel structure, another key parameter to model fire behaviour is the moisture content of the fuel particles. Fuel moisture content affects their rate of combustion, influencing fire intensity and spread. Dead fuels moisture content highly depends on daily weather changes, whereas live fuels moisture content is more influenced by seasonal weather changes. We used fuel moisture scenarios defined in Scott and Burgan 2005 as input for the simulation (Table 3), following RCP emissions approach (Moss et al., 2010).

Table 3. Moisture content of dead and live fuels per climate scenario used for the simulations.

	Time Slice	Period	1h	10h	100h	Herbs	Shrubs	
RCP 4.5	2021 – 2050	Short	9	10	11	90	120	Moderate
	2051 – 2069	Mid	6	7	8	60	90	Low
	2070 – 2099	Long	6	7	8	60	90	Low
RCP 8.5	2021 – 2050	Short	9	10	11	90	120	Moderate
	2051 – 2069	Mid	6	7	8	60	90	Low
	2070 – 2099	Long	3	4	5	30	60	Very Low

Weather data includes measures of temperature, relative humidity, precipitation, wind speed, and wind direction. We modelled fire behaviour using RCP 4.5 and RCP 8.5 scenarios for the intervals 2021-2051 (short-term), 2052-2069 (mid-term), and 2070-2100 (long-term) (Taylor et al., 2012). We used average weather values from January, February, and March, as these are the driest months and the peak of the fire season in Bhutan (Chhetri, 1994). Minimum and maximum temperature were taken from downscaled projections of the MIROC5 climate model. Precipitation was set at 0 for all scenarios. We created relative humidity scenarios using historical records for the period 1989-2019 (Hydromet, 2020). Periods 2021-2051 and 2052-2069 were constructed using the 75th and 85th percentile of relative humidity for both RCP scenarios, respectively, and period 2070-2100 was constructed using the 85th percentile for RCP 4.5 and the 97th percentile for RCP 8.5.

Fire behavior models are a very useful tool to spot areas with higher fire risk. However, some important factors that also affect fire behavior are overlooked by the models, for example mistletoe presence and coarse dead wood, and must be acknowledged when interpreting simulation results.

4.3 Quantifying and Prioritizing Risks & Vulnerability

We first classified both ‘flame length’ and ‘rate of spread’ under 4 classes in ArcGIS using the Natural Breaks (Jenks) function which assigns classes to minimize the squared deviation within each class. We then combined the classes of both ‘flame length’ and ‘rate of spread’ to come up with four risk classes: ‘low’, ‘medium’, ‘high’, and ‘very high’.

Using R and ArcGIS, we extracted forest areas under the four risk classes, for both RCP scenarios and the three time slices. We took forest areas as a proxy for risks to biodiversity. And to estimate risks to production circles, we quantified the number of houses which fall under different risk categories.

Rural Household and rural infrastructure locations were obtained from the Population and Housing Census of Bhutan 2005 (PHCB 2005) data collection. The household and rural infrastructure locations have been published in the Atlas of PHCB 2005. We used the 2005 data instead of the more recent 2017 data since GPS points for individual infrastructure is only available for 2005. We assume that using the actual GPS points would render us a much more accurate estimate of actual households under risks in different Gewogs of Bhutan. We also used GPS locations for religious structures and educational institutes available with the National Land Commission Secretariat (NLCS) of the Royal Government of Bhutan.

We ranked Gewogs at higher risk for the 2021-2050 time slice, combining the information about forests and households at risk, to prioritize areas where adaptation measures should be first taken. To focus our presentation of results, we combined ‘high’ and ‘very high’ risk classes and present them as high risk areas.

4.4 Implications of ‘Fire Environment’ Assumptions

Future fire potential in Bhutan will depend on the frequency, timing, and density of ignitions as well as the actual fire environment. The influence of lightning on ignitions will remain uncertain and is largely beyond the influence of policy and management. The potential for human-caused ignitions is the subject of fire prevention programs. In modeling future fire potential, we have looked only at the potential changes in the fire environment. Fire modeling in climate change scenarios involves making assumptions about the future fire environment: climate/weather, vegetation/fuels, and terrain influences. We recognize that daily, seasonal, and decadal variations in precipitation, relative humidity and wind are unknown currently. We have assumed that there will be significant periods of time in future climates where fire weather will be conducive to fire spread under the various RCP scenarios.

A critical element in this assessment is the projection of future fuel beds. We have used general fire regime and vegetation dynamic principles to guide selection of future fuel conditions. The selection fuel models are inherently subjective. The fuel models are mathematical expressions of fuel bed properties. They are an agglomeration of living and dead vegetative elements. Fire potential varies with changes in the chemistry and physical properties of these elements in three-dimensional space, not the species composition per se. Globally, biomes exhibit repeating patterns of vegetation physiognomy and fuel bed properties. The 40 fuel models in Scott and Burgan (2005) represent a robust range of identifiable fuel beds to a level of detail sufficient to support management and policy decisions. Our selection of future fuel beds is consistent with observed patterns elsewhere in the world. They are, however, provisional and should be subjected to place-based synthesis and refinement.

Chapter V: Results – Increasing Risks from Forest Fires & Implications

To frame adaptation strategies for the next decade, we focused on highlighting results for the short time frame (now till 2050) under the RCP 4.5 scenario. Detailed results in the main text are mostly limited to projections for RCP 4.5 from now till 2050. Results for other scenarios and time slices are appended in the form of consolidated GIS maps and datasheets. We combined ‘high’ and ‘very high’ risk classes under one single high fire risk category, and present results as such.

5.1 Causes, Current and Historical Extent of Forest Fires

Forest fires in Bhutan continue to take a substantial toll on wildlife and biodiversity with annual fire incidences averaging about 57 events (Figure 5) and scarring an average of about 200 ha annually¹. These forest fires are not evenly distributed across the country (Map 2), with Dzongkhags such as Thimphu, Wangdue Phodrang, Punakha, Mongar, Lhuentse and Trashigang seeing the most fires (Map 3).

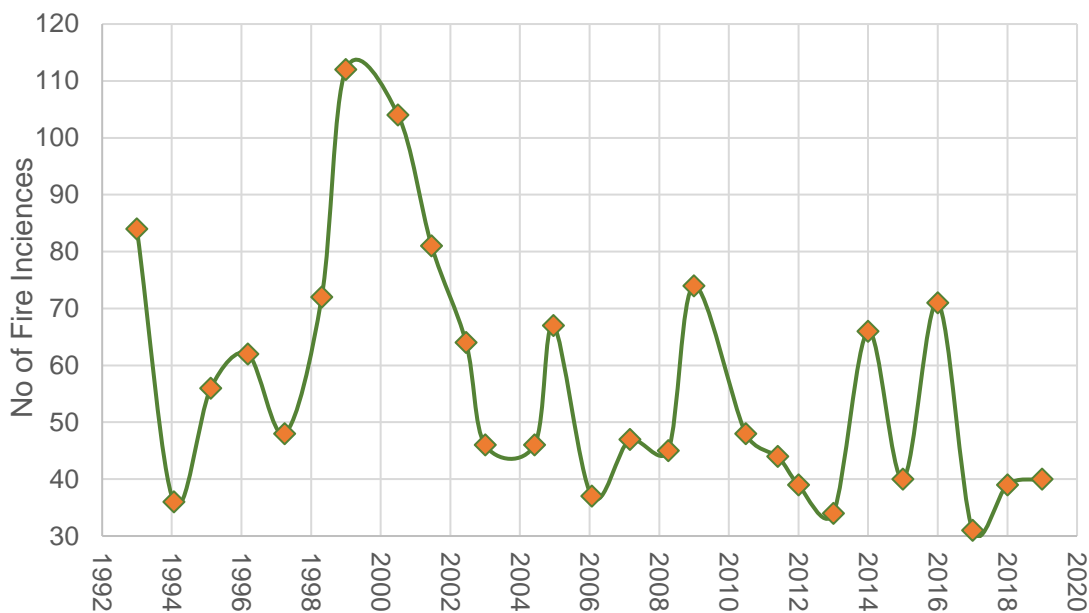


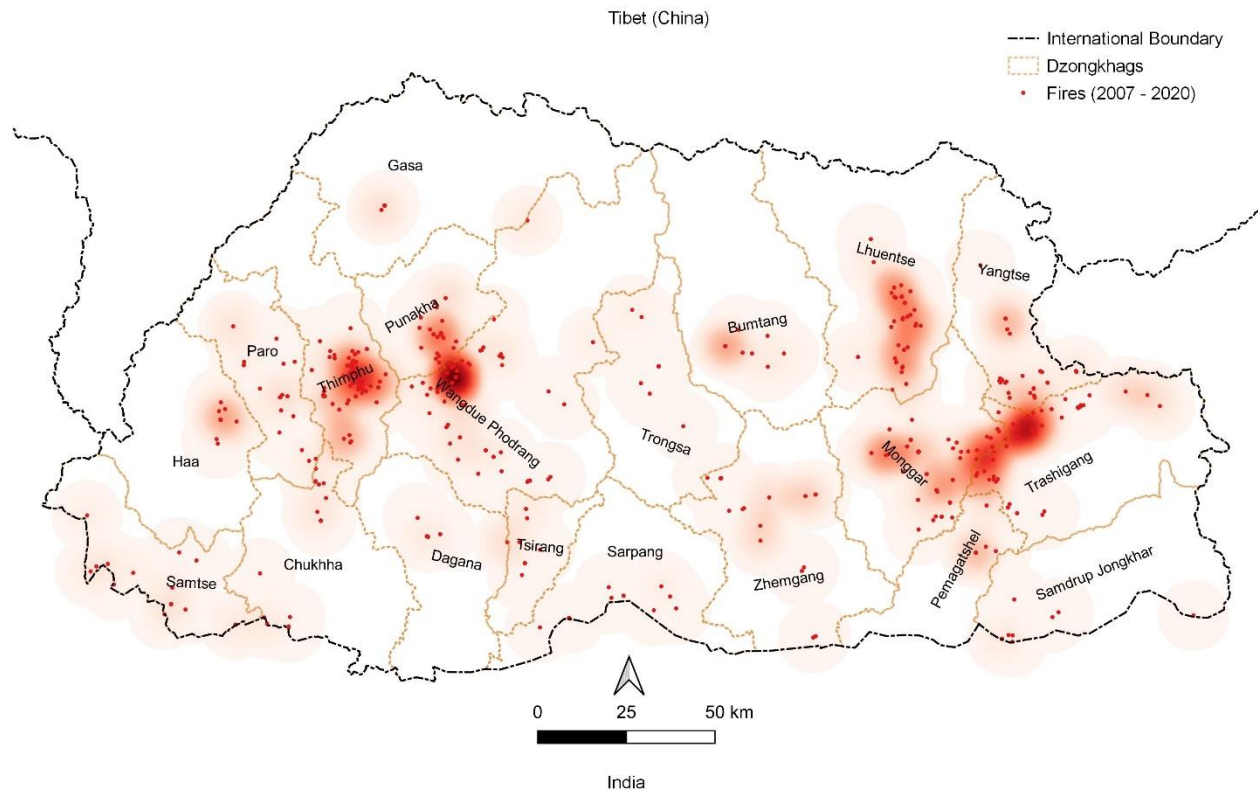
Figure 5. Number of fire incidences from 1992 till 2019

Records maintained at the Department of Forests and Park Services (DoFPS) show the following to be the main cause of forest fires in Bhutan.

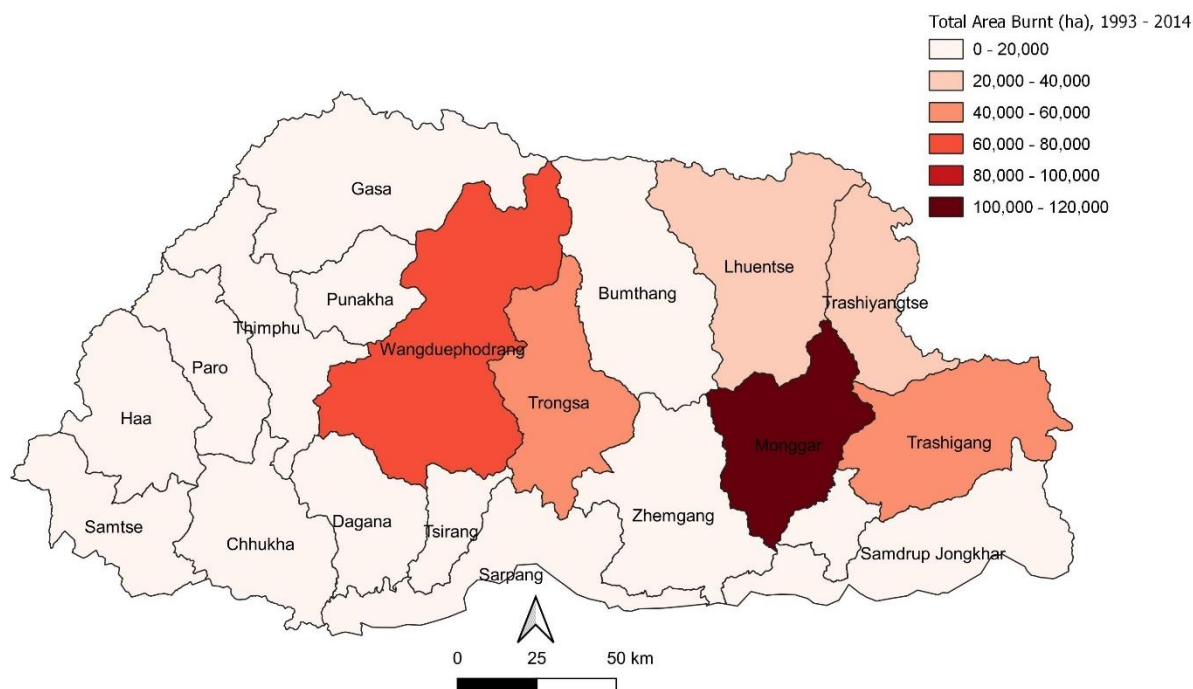
- Agriculture debris burning
- Children playing with ignition source (such as matchsticks)
- Lemon grass harvesters

¹ Average tabulated for fire events from 1993 to 2014. Data sourced from DoFPS.

- Smokers
- Cattle herders for new grass
- Roadside workers
- Picknickers
- Campfires
- Electric short circuit



Map 2. Fire occurrence locations (2007-2020) and current fire risk zones. Darker shades correspond to higher fire occurrences and more area burnt.



Map 3. Total forests burnt (hectares) from 1993 till 2014

Current fires are mostly concentrated in the chir pine and blue pine zones forests, with occasional fires within sub-tropical broadleaved forests.

5.2 Forests and Biodiversity at Increased Risk

Both flame length and rate of fire spread experience an increase as climate becomes more extreme (Figure 6 & 7). We chose ‘flame length’ as a unit of measure for comparing results across different scenarios. The flame length metric also accounts for crown fires, and crown fires are an important factor in determining the rate of spread. Thus, flame length and rate of spread capture the dynamics of expected changes, and indicate fire severity under future climate scenarios. Although, ground fires are an important factor in fire severity, ground fires are not modeled by the current system since we do not have the data to calculate depth of burn. It is, however, important to recognize that depth of burn is important for post fire vegetation dynamics, potential post fire erosion, and for calculating a site’s carbon mass.

According to our simulations, chir pine forests experienced the most severe fire behavior, with flames reaching 2.2 m length and spread of fire at 8.9 m min^{-1} for the RCP 8.5 scenario period 2070-2100. Besides chir pine forests, the highest flame length values were found in mixed conifer forests, with flames reaching also 2.2 m length, and the fastest spread in broadleaf forests below 2000 m, with a fire line moving at 6.4 m min^{-1} . Fir forests and broadleaf forests above 2000 m underwent the mildest fire behavior outputs.

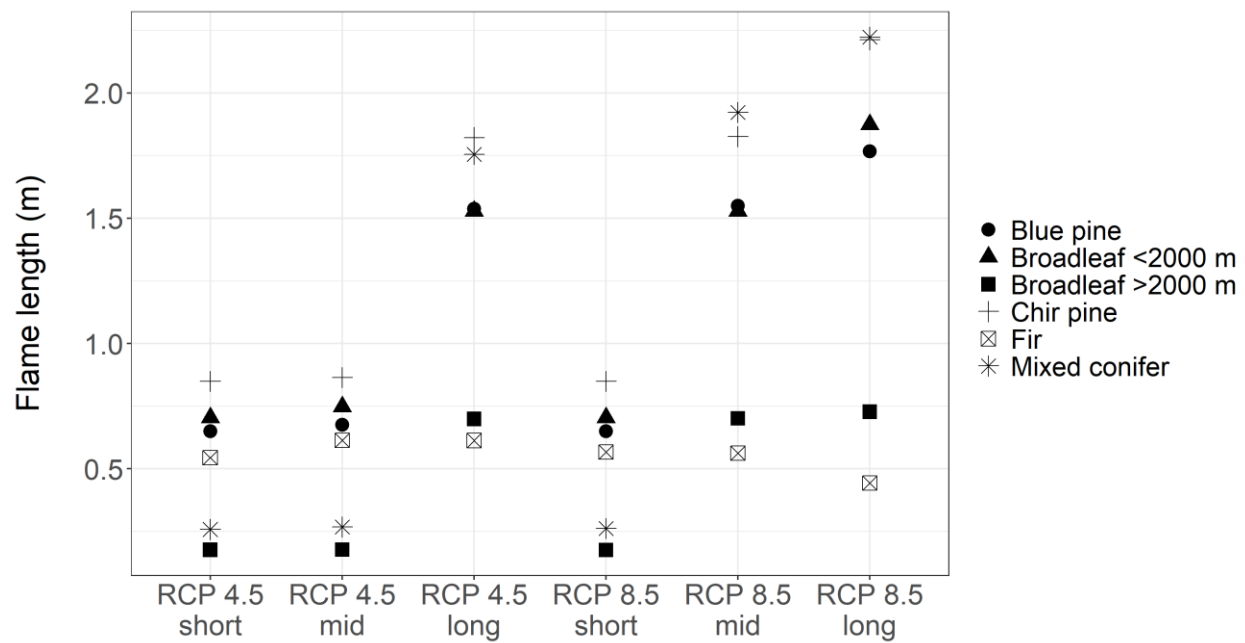


Figure 6. Predicted flame length (m) under RCP 4.5 and RCP 8.5 across 3 time slices

Fire behavior spiked in those scenarios where the fuel model accounted for an increase in fuel load because of warmer temperatures and longer growth period (Table 2 and 3).

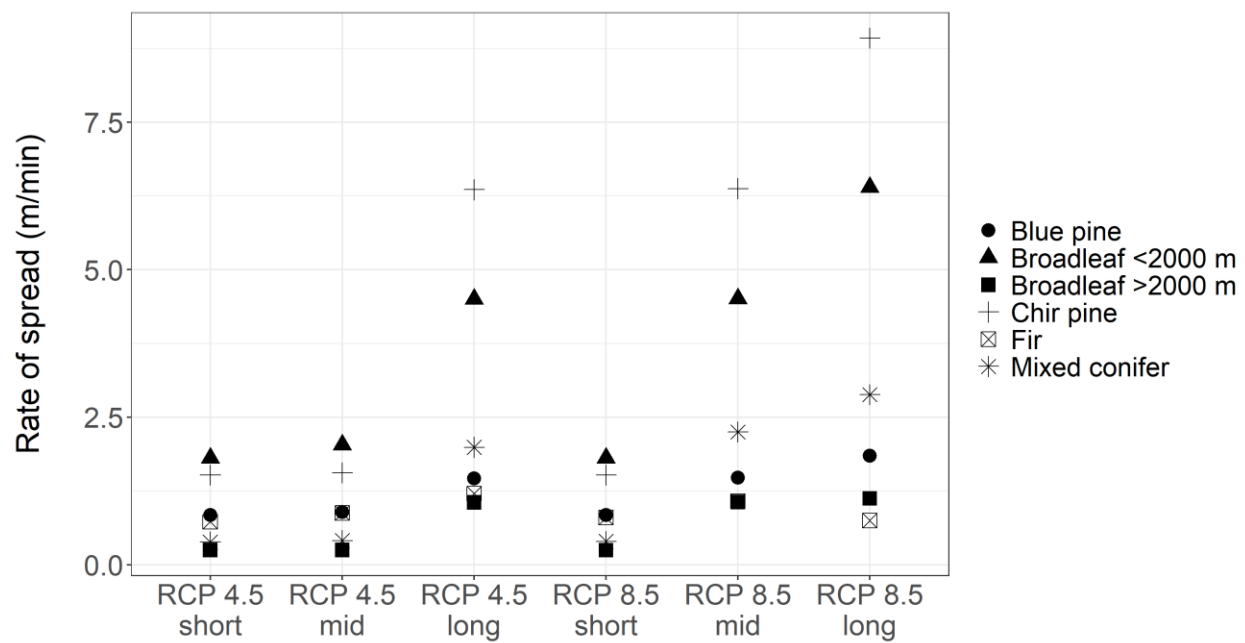


Figure 7. Predicted 'rate of spread' (m/min) under RCP 4.5 and RCP 8.5 across 3 time slices

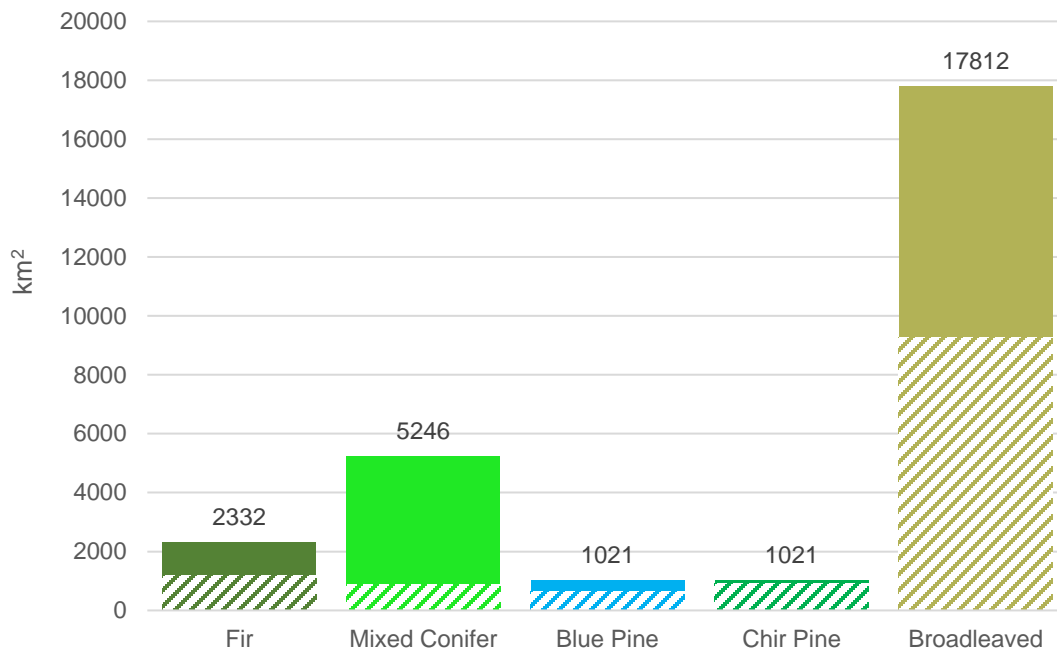
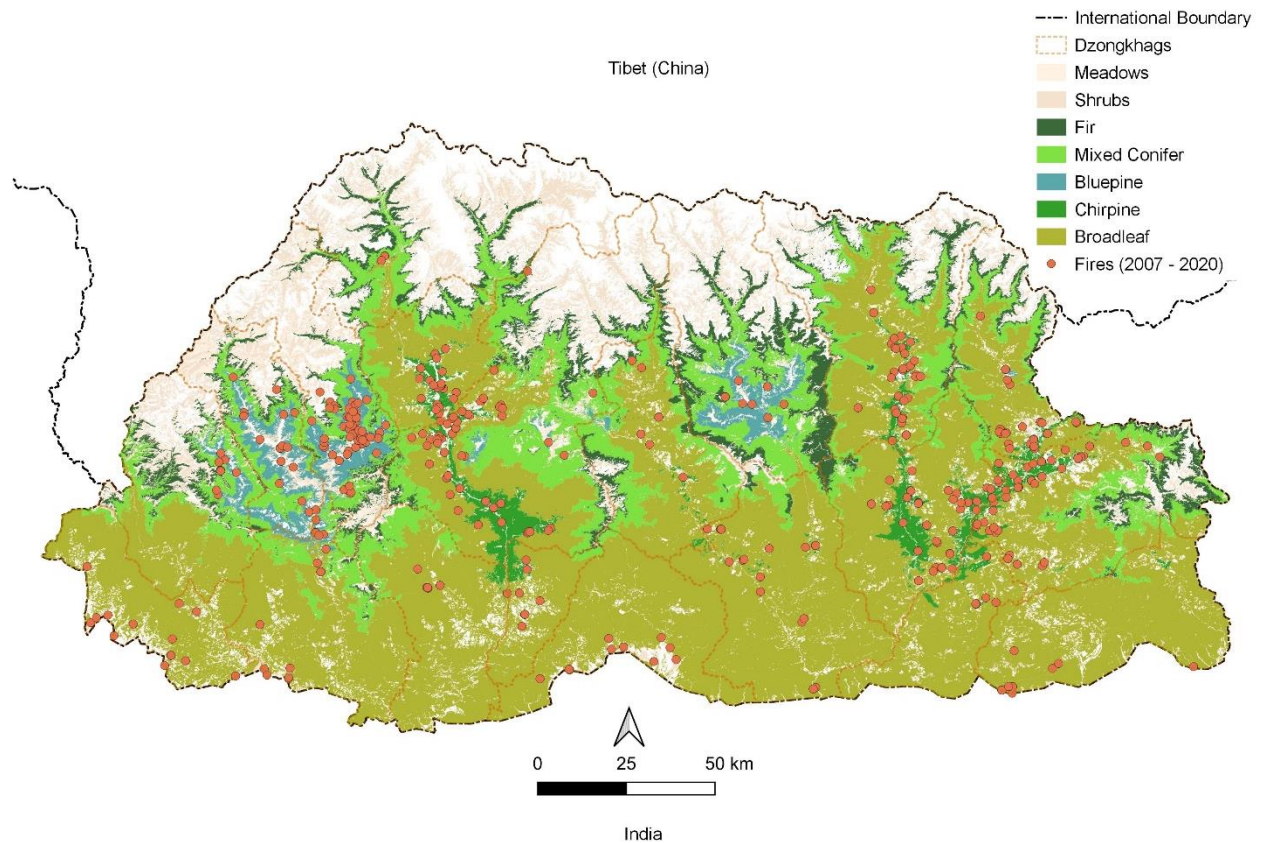


Figure 8. Forest types, area coverage, and portion under risk (shaded) in each forest type from now till 2050

Almost 90% of Chir pine forests fall under high risk from now till 2050 followed by blue pine with over 60% being subjected to high risk. See Figure 8 and Map 4.



Map 4. Forest types and fire locations

5.3 Implications on Biodiversity

Chir pine, blue pine and mixed conifer forests will be the most impacted according to our model projections (Figure 9). Given the size of broadleaved forests (Map 4) and the fuel models we used, broadleaved forests below 2000 masl show up to be at most risk. Given that these broadleaved forests are currently not subject to frequent and intensive forest fires, forest composition and biodiversity in these forests will be severely impacted should fires do occur at the projected rates.

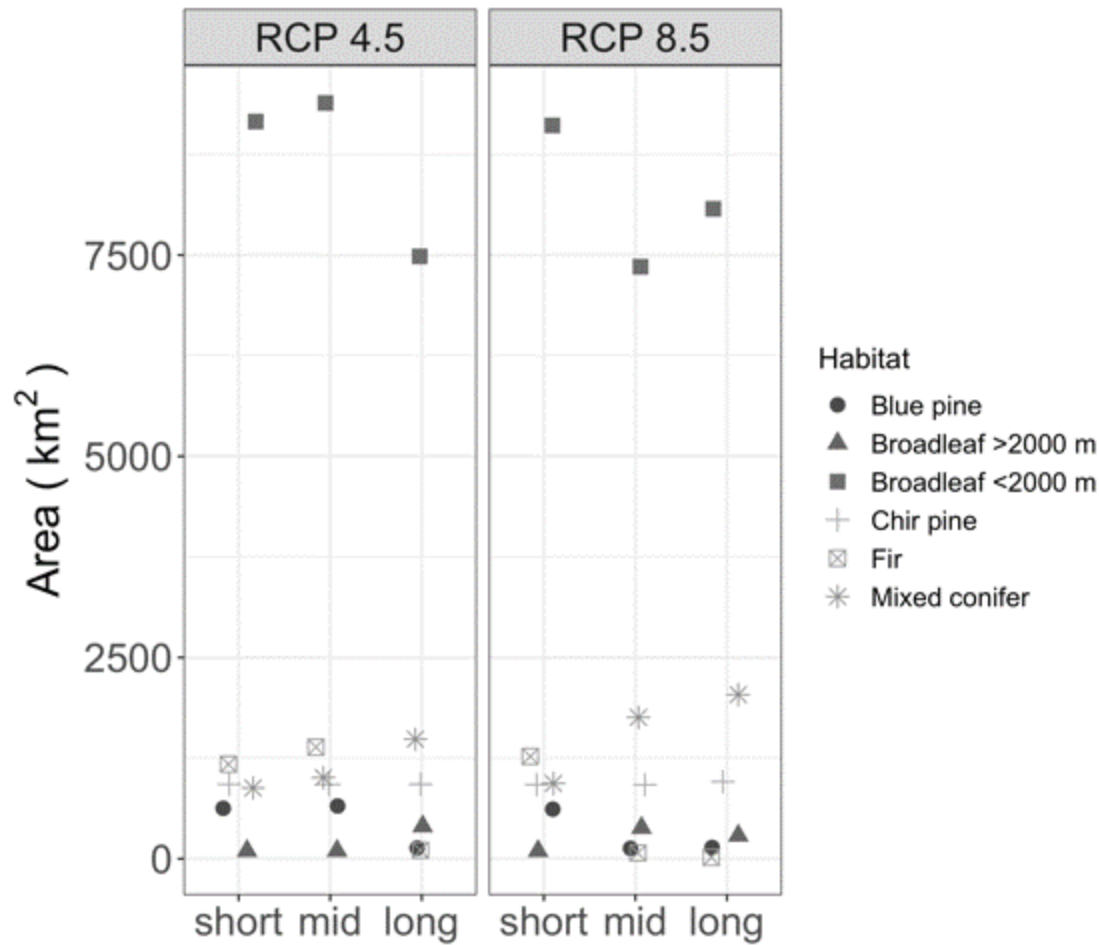


Figure 9. Forest areas (km²) at risk under RCP 4.5 and RCP 8.5 across 3 time slices

5.3.1 Chir pine, Blue Pine, Mixed conifer & Fir Forests

Under RCP 4.5, from now till 2050, an estimated 921 km² of chir pine, 626 km² of blue pine, 879km² of mixed conifer forests, and 1175 km² of fir forests will be at high fire risk (Table 4). Areas under high fire risk increase significantly for mixed conifer forests for all time slices and under both RCP 4.5 and RCP 8.5.

Areas under risk appear to decline and remain constant for blue pine and chir pine forests respectively across time slices and RCP scenarios, yet in mixed conifer forests risk areas increase. See Table 4.

Table 4. Chir pine, blue pine, mixed conifer and fir forests at risk under RCP 4.5 and RCP 8.5 across 3 time slices

Time Slice	Chir pine (km ²)		Blue pine (km ²)		Mixed conifer (km ²)	Fir (km ²)	RCP 4.5	RCP 8.5
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5				
short	921	921	626	616	879	935	1175	1271
mid	924	956	655	128	1009	1756	1387	71
long	926	956	133	139	1486	2039	106	17

Athang and Daga Gewogs in Wangdue and Saleng Gewog in Mongar are at most risk within the Chir pine zone (Table 5) in the short time frame (now till 2050). A full ranking of Gewogs at risk within the chir pine zone is presented in Annex 1.

Table 5. Ten Gewogs at most risk (area burnt in km²) from fires within Chir pine forests (now till 2050)

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Athang	118	117
Daga	81	81
Saleng	66	66
Patala	37	37
Udзорong	34	34
Shumer	31	31
Drepung	25	25
Narang	25	25
Kengkhar	25	25
Ruepisa	23	23

Two Gewogs of Mewang and Kawang in Thimphu are at most risk followed by Chhoekhor Gewog in Bumtang within the Blue pine forest zone. See Table 6. A full ranking of Gewogs at risk within the blue pine zone is presented in Annex 2.

Table 6. Ten Gewogs at most risk (area burnt in km²) from fires within the blue pine forests (now till 2050)

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Mewang	69	68
Kawang	57	56
Chhoekhor	50	49
Naja	41	41
Chhume	41	40
Chang	39	38
Tsento	37	37
Tang	37	36
Doga	28	27
Chapchha	25	25

Kazhi in Wangdue and lower reaches of Lunana Gewog show up as being at most risk followed by Langthil Gewog in Trongsa and Athang in Wangdue within the mixed conifer forest zone. See Table 7. A full ranking of Gewogs at risk within the mixed conifer zone is presented in Annex 3.

Table 7. Ten Gewogs at most risk (area burnt in km²) from fires within the mixed conifer forests (now till 2050)

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Kazhi	49	54
Lunana	48	53
Langthil	35	36
Athang	35	36
Kurtoe	32	37
Bumdeling	31	34
Tseza	31	31
Toewang	28	30
Nubi	27	28
Merak	26	26

Within the fir zone, Choekhor and Lunana Gewogs followed by Sephu in Wangdue Phodrang and Tang in Bumtang are projected to be at most risk (Table 8). A full ranking of Gewogs at risk within the fir zone is presented in Annex 4.

Table 8. Ten Gewogs at most risk (area burnt in km²) from fires within fir forests (now till 2050)

Gewog	RCP 4.5	RCP 8.5
Chhoekhor	78	94
Lunana	66	73
Sephu	65	72
Tang	63	67
Kazhi	56	63
Bumdeling	56	58
Sakteng	55	56
Bji	53	58
Laya	52	62
Kurtoe	51	58

5.3.2 Broadleaved Forests

Risks to broadleaved forests at lower elevations (<2000) are projected to increase from now to 2050 with over 9000 km² of broadleaved forests at high fire risk under both RCP 4.5 and RCP 8.5. The area under risk remains fairly constant under both RCPs as we approach the end of this Century. See Table 9.

Table 9. Broadleaved forests at risk under RCP 4.5 and RCP 8.5 across 3 time slices

Time Slice	BL > 2000 (km ²)		BL < 2000 (km ²)	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
short	97	97	9159	9111

mid	99	384	9390	7355
long	403	287	7484	8075

Pangkhar Gewog in Zhemgang and Athang in Wangdue followed by Jigmichhoeling in Sarpang and Trong Gewog in Trongsa have the most area at risk from fires within broadleaved forests below 2000 masl. See Table 10. A full ranking of Gewogs at risk within the mixed conifer zone is presented in Annex 4.

Table 10. Ten Gewogs at most risk (area burnt in km²) from fires within the broadleaved forests below 2000 masl (now till 2050)

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Pangkhar	460	457
Athang	292	294
Jigmichhoeling	288	286
Trong	259	258
Saleng	219	218
Bongo	209	208
Nangkor	202	201
Serthig	199	198
Ngangla	187	186
Bjoka	176	175

5.4 Production Circles at Increased Risk

5.4.1 Houses at Risk

A total of 18490 households will be at increased risk from forest fires under RCP 4.5 as we move from now to 2050 (Table 11).

Table 11. Households at high fire risk under different RCPs and time slices

	Short	Med	Long
RCP 4.5	18490	19516	11782
RCP 8.5	18203	11347	13951

Houses within the broadleaved belts below 2000 masl will be at most risk from now until 2050, followed by households within chir pine and blue pine zone. There are no households and infrastructure at risk within mixed conifer, fir, and broadleaved forests above 2000 masl. See Figure 10.

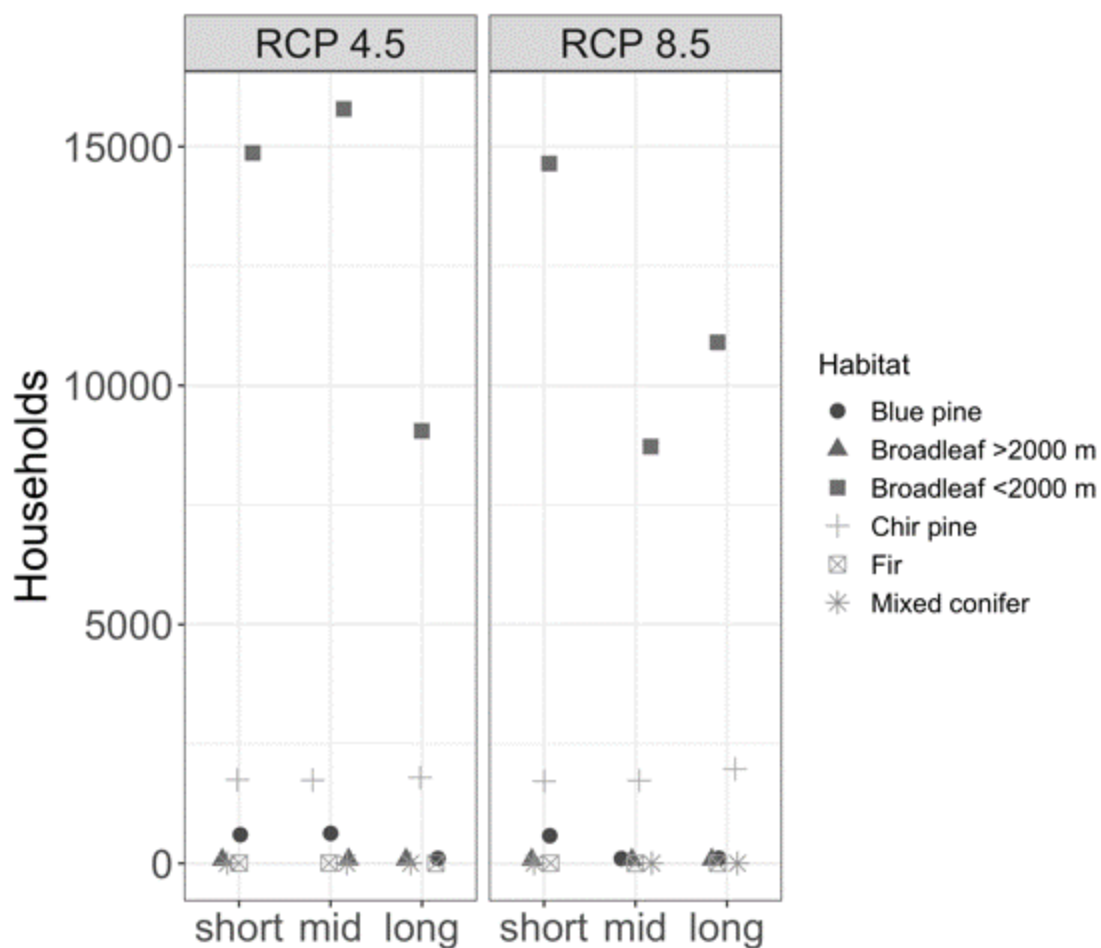
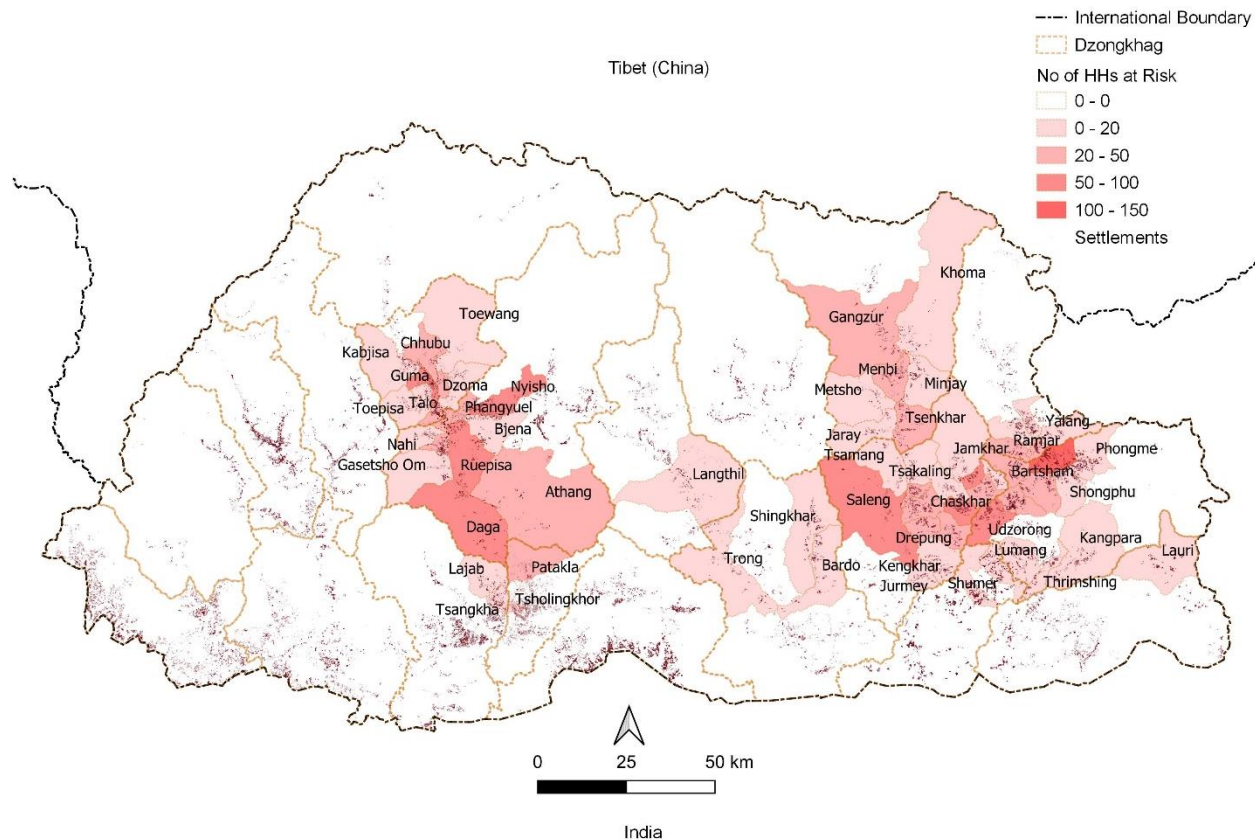


Figure 10. HHs at risk under RCP 4.5 and RCP 8.5 across 3 time slices

An estimated 1747 households will be at a high fire risk within the chir pine zones under RCP 4.5 as we move from now till 2050 (Table 12 & Map 5). See Annex 6 for a full list of Gewogs at most risk in chir pine forests.

Table 12. Gewogs (top 10) at most risk in Chir pine forests under RCP 4.5 from now till 2051

Gewog	Dzongkhag	Households
Bartsham	Trashigang	112
Bidung	Trashigang	110
Daga	Wangduephodrang	91
Ruepisa	Wangduephodrang	74
Balam	Monggar	62
Saleng	Monggar	62
Udzorong	Trashigang	59
Nyisho	Wangduephodrang	58
Chaskhar	Monggar	56
Guma	Punakha	52

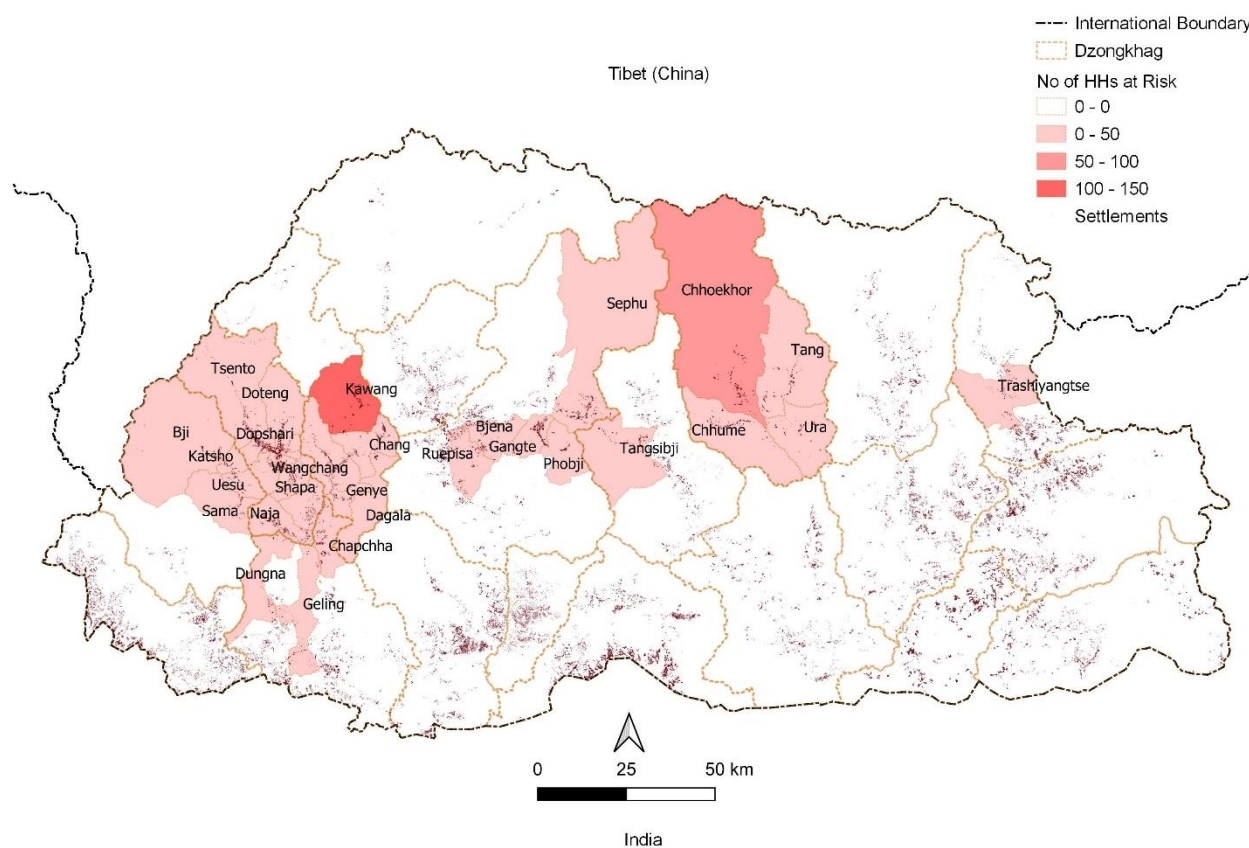


Map 5. Gewogs with most HHs at risk from fire (from now till 2050) in the Chir pine forest zone

An estimated 598 households will be at a high risk within the blue pine zones under RCP 4.5 as we move from now till 2050 (Table 13 & Map 6). Refer Annex 7 for a full ranking of Gewogs at most risk under blue pine forests.

Table 13. Gewogs (top 10) at most risk in blue pine forests under RCP 4.5 from now till 2051

Gewog	Dzongkhag	Households
Kawang	Thimphu	108
Chhoekhor	Bumthang	54
Chang	Thimphu	44
Chapchha	Chhukha	43
Naja	Paro	38
Tsento	Paro	38
Mewang	Thimphu	26
Uesu	Haa	22
Tang	Bumthang	21
Gangte	Wangduephodrang	19

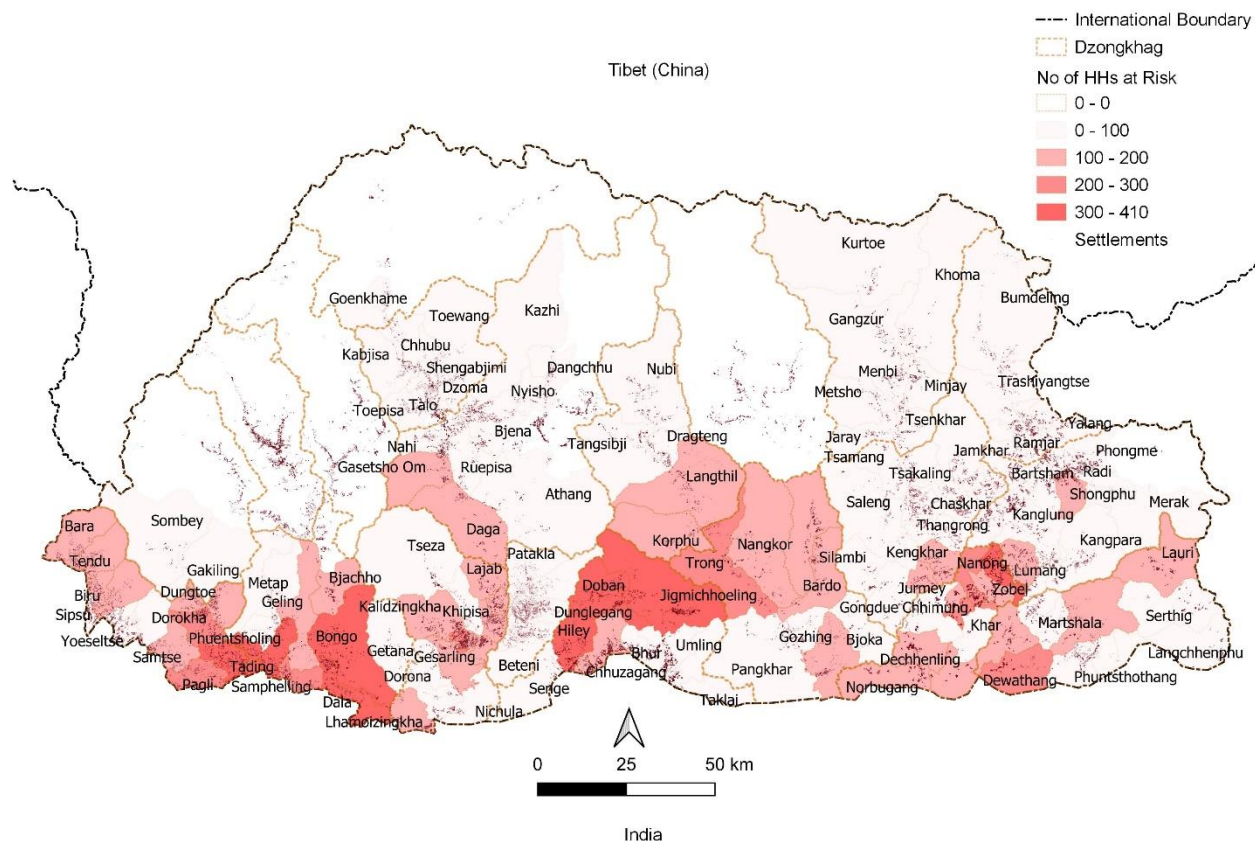


Map 6. Gewogs with most HHs at risk from fire (from now till 2050) in the blue pine forest zone

About 14867 households will be at a high risk within the broadleaved forests below 2000 masl under RCP 4.5 as we move from now till 2050 (Table 14 and Map 7).

Table 14. Gewogs (top 10) at most risk in broadleaved forests below 2000 masl under RCP 4.5 from now till 2051

Gewog	Dzongkhag	Households
Jigmichhoeling	Sarpang	408
Hiley	Sarpang	395
Bongo	Chhukha	373
Phuentsholing	Chhukha	373
Dala	Chhukha	362
Tading	Samtse	362
Doban	Sarpang	304
Nanong	Pema Gatshel	301
Shumer	Pema Gatshel	292
Dewathang	Samdrup Jongkhar	278



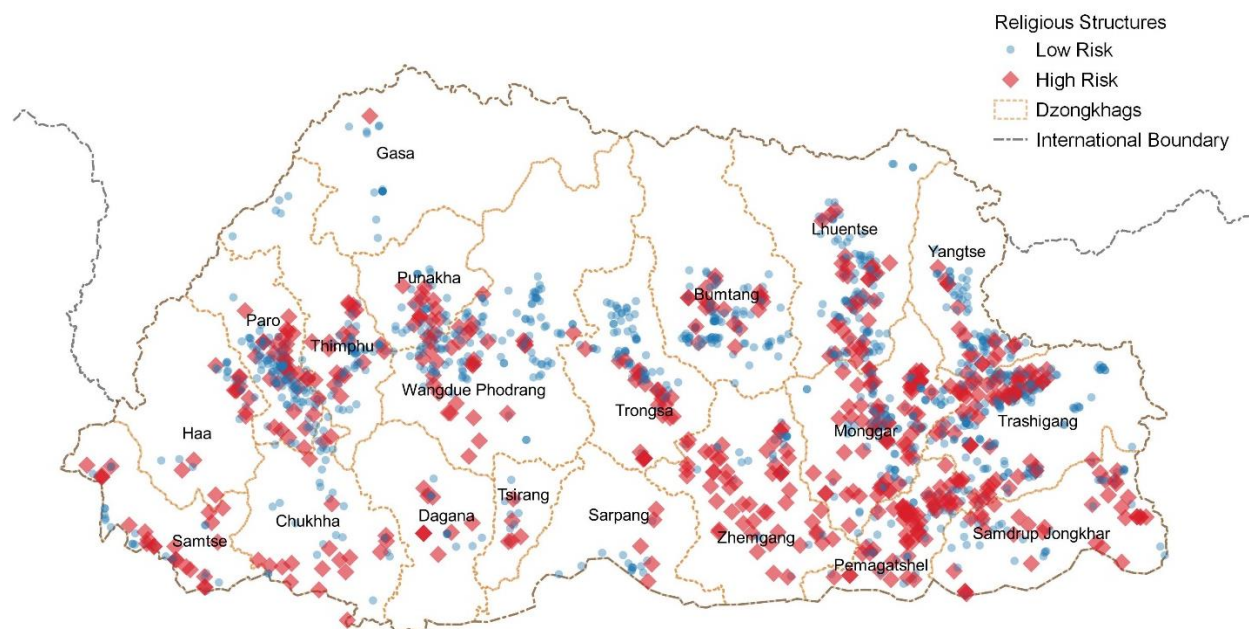
Map 7. Gewogs with most HHs at risk from fire (from now till 2050) in the broadleaved forests below 2000 masl

5.4.2 Religious Structures at Risk

Of the 1774 religious structures currently recorded at the National Land Commission Secretariat (NLCS), a total of 549 (30%) religious structures will be at risk under RCP 4.5 from now till 2050. See Table 15 and Map 8.

Table 15. Gewogs (top 10) with most religious structures at risk under RCP 4.5 from now till 2051

Gewog	Dzongkhag	Number	Forest Type
Nangkor	Zhemgang	13	Broadleaved (<2000 masl)
Shongphu	Trashigang	12	Broadleaved (<2000 masl)
Chhoekhor	Bumthang	10	Blue pine
Shermung	Monggar	10	Broadleaved (<2000 masl)
Yurung	Pema Gatshel	10	Broadleaved (<2000 masl)
Bardo	Zhemgang	10	Broadleaved (<2000 masl)
Serthig	Samdrup Jongkhar	9	Broadleaved (<2000 masl)
Zobel	Pema Gatshel	8	Broadleaved (<2000 masl)
Kawang	Thimphu	8	Blue pine
Langthil	Trongsa	8	Broadleaved (<2000 masl)



Map 8. Religious structures at risk under RCP 4.5 from now till 2050

Annex 9 shows gewogs with the most religious structures at risk, while Annex 10 presents details of individual structures at risk by gewogs and dzongkhags.

Chapter VI: Adapting to Increased Forest Fire Risks

6.1 Risk Summary, Recommendation Time Frame and Priority Adaptation Areas

As per the findings presented prior, in the short-term, the risk of forest fire is most at the mid-altitudes in the temperate montane forests. The risk extends to the subtropical vegetation zone in the mid to long-term. Under RCP 4.5, in the next 30 years, in the temperate zone, an estimated 626 km² of blue pine, 921 km² of chir pine and 879 km² of mixed conifer forests will be at high risk. Risks to broadleaved forests at lower elevations (<2000) are projected to increase from now to 2050 with over 9000 km² of broadleaved forests at high fire risk under both RCP 4.5 and RCP 8.5.

These temperate and broadleaved forests mostly occur along mid and interior valleys and remain vital as sources for timber and other forestry resources. These forests are also home to a significant portion of the eastern Himalayas' rich biodiversity. Concurrently, since settlements within these valleys are located close to forest areas, forest fires pose increased threat to people and property.

Both flame length and the rate of fire spread are expected to increase in all forest types (except for fir) under both RCP 4.5 and RCP 8.5, and for all time slices. This means that forest fires will be more intense with increasing possibility of more crown fires. Coupled with a faster rate of spread, the possibility of larger fires burning over longer periods is an imminent possibility.

In the short (10 years) to medium-term (30 years), given the impending risks, adaptation efforts should be ramped up in high-risk forest types and settlements identified in the analyses and mentioned in the following table (Table 15).

Table 16. A summary of Gewogs at most risk in terms of forest areas and settlements exposed to high fire risk

No	Forest Types/ Settlements	Focus Gewogs
1	Chir pine forest	Athang, Daga, Saleng, Patala, Udorong, Shumer, Drepung, Narang, Kengkhar, Ruepisa
2	Blue pine forest	Mewang, Kawang, Choekhor, Naja, Chhume, Chang, Tsento, Tang, Doga, Chapchha
3	Mixed conifer forest	Kazhi, Lunana, Langthil, Athang, Kurtoe, Bumdeling, Tseza, Toewang, Nubi, Merak
4	Broadleaved forest	Pangkhar, Jigmichhoeling, Trong, Bongo, Serthig, Ngangla, Bjokha, Nangkhor, Langchhenphu, Senge
5	Settlements in chir pine forests	Bartsham, Bidung, Daga, Ruepisa, Balam, Saleng, Udorong, Nyisho, Chaskhar, Guma
6	Settlements in blue pine forests	Kawang, Chhoekhor, Chang, Chapchha, Naja, Tsento, Mewang, Uesu, Tang, Gangte

6.2 Strengthen Adaptive Fire Management

Pro-active management within high risk areas such as chir pine, blue pine and broadleaved forests (< 2000 masl) is an immediate requirement. The advent of formal forestry institutions and active enforcement of regulations which restricted resource use and favored formal suppression efforts has led to steady fuel load accumulation in the forests since the early 1950s. See Plate 3. Under a warming climate, such accumulation of fuel load will continue to put Bhutan's forests at an increased risk to forest fires.



Plate 1. Fuel build-up one year after fire in a blue pine forest

6.2.1 Fuel Load Management

An adaptive framework for forest fuel management at the national scale will be useful to mitigate severe fire risks across all time-scales. Reduction of available fuel can be achieved either through controlled concessionary rights (rural resource collection plans, regulated grazing), through silvicultural thinning, or through application of cost-effective prescribed burn techniques. All such measures should be outlined within Local Forest Management Plans (LFMP's).

We recommend fuel load management in both chir pine and blue pine forests. Within chir pine forests, controlled burning should be encouraged particularly within lemon grass growing areas. Research into optimal burning cycles, seedling recruitment, burn intensity, mortality and recovery rates, should be initiated immediately to provide management recommendations. The National Forest Policy of 2011 allows for active use of fire as an ecosystem management tool.

Within blue pine forests, scientifically determined thinning prescriptions should be implemented to reduce forest flammability and encourage tree growth to meet economic purposes. Traditional forest management systems which encouraged multiple-use of forests by rural communities for food, fodder, fuel, timber, and grazing, would have reduced available forest fuel, thereby averting severe and catastrophic fires. Research should also be initiated on how grazing practices mediate forest fuel availability.

6.2.2 Forest Fire Line Creation

Fuel load management should be supplemented by the creation of large-scale spatial breaks of fuel complexes. Projected flame lengths could be used to guide the design and dimensions of such breaks.

These discontinuities/breaks can be established in the forest periphery and urban interface or inside the forest. Such arrangement will stop low and medium intensity fires from spreading to larger landscapes. However, it should be noted that creation of fire lines, in and of itself, is not a full-on solution to combating forest fires. High intensity fires may jump over these breaks and strong winds can reduce the effectiveness of such breaks, as flying embers carried by the wind easily cross over, and light a spot fire on the other side.

However, fuel breaks and fire breaks can be very effective if properly installed, maintained and used. The design and maintenance of these fire lines should carefully noted, and their impact on wildlife, access to the forest by people, and potential erosion, should be considered. A comprehensive fire line creation plan should be developed and mainstreamed within the DoFPS's five year plans.

6.2.3 Post Fire Habitat Management

In most cases, post fire, burnt areas are left to recover through natural regeneration. However, in areas where the burn severity is high, vegetation does not regenerate at all or takes a long time to do so. Given our predictions of higher intensity and longer burn durations, it will be necessary to intervene and ensure adequate regeneration of burnt areas.

Post fire, technical assessments of burn severity should be mandatory. The DoFPS has conducted preliminary works on burn severity assessments using the MTBS (Monitoring Trends in Burn Severity) framework developed by the USDA Forest Service. The MTBS program should be mainstreamed within annual workplans of the DoFPS, and implemented routinely, as and when fires occur, to define and prescribe rehabilitation measures.

6.3 Secure Infrastructure at Risk

As forest fire intensity, size, and duration of burn increases, there is imminent danger to rural settlements and expanding urban infrastructure. The need for ensuring fire-safe communities is ever more relevant in Bhutan, given that over 70% of Bhutan's land area remains under forest cover. Majority of the human settlements interface directly with forested areas, and important cultural and historical national assets (i.e. Dzongs, Lhakhangs) are almost always located in far-flung forested areas. See Plates 4 and 5.



Plate 2. Wildland-urban interface



Plate 3. Fire below Wangditse Dzong above Thimphu in 2021

Adaptation and fire risk mitigation measures should be actively pursued to protect communities and important national infrastructure, where risk of ignition or spread from adjoining forest areas is high. The DoFPS has already initiated some preliminary measures in this area by clearing risk trees and bushes around important religious and cultural sites such as the Semthokha Dzong.

In all such cases, woody fuels should be removed for 10 meters around these structures. In addition, remaining trees and large shrubs should be pruned carefully to raise the crowns 1-2 meters above the ground surface. Water storage systems and fire hydrants should be built around key infrastructure supported by solar powered systems, incase of breakdown in energy supply systems. Fire safety protocols to minimize risk and contain fire outbreaks should be developed and distributed to all facilities at risk.

6.4 Reduce Forest Fire Causes

Any adaptation measure, especially in the shorter timeframe should also give due recognition to the causes of forest fires in Bhutan. One of the major causes of forest fire is sparks generated by electrical short circuits from powerlines and old transformers. See Plates 6 and 7.



Plate 4. Transformers cause fire



Plate 5. A fire close to Tashichhodzong sparked by electrical short circuit

Throughout Bhutan, cross-country electrical transmission and distribution corridors have not been maintained properly and cleared of woody vegetation. These corridors need to be systematically maintained and cleared of trees and shrubs over 2 meters tall. In major wind events, arising from climate change in future, electrical wires can swing wildly, cross and short-out or touch adjacent vegetation, leading to a wildland ignition or multiple fires all along the route of a blown-down line. These fires can spread quickly and become thousands of hectares in size. A systematic maintenance program for such corridors needs to be established in consultation with relevant stakeholders including DGPC, DHPS and BPC. Simple interventions on choice of dwarf fire resistant tree/shrub species in powerline corridors and use of modern drone aircraft can make regular inspections affordable and doable.

Apart from the cases relating to electrical short circuits, almost all fires are caused by people and their activities. The DoFPS continues to pursue public awareness and education campaigns. These campaigns should be aimed at eliciting behavioral changes in addition to disseminating information on ecosystem consequences and legal implications. The programs should also educate and train communities to get prepared for, and mitigate, risks from wildfires.

6.5 Strengthen Response Capability

6.5.1 Forest Fire Suppression Equipment

As forest cover increases in Bhutan due to wide scale planting of conifers and fire exclusion, fuels will increasingly become woody fuels, not grasses, rendering pine boughs essentially useless for fire suppression. The longer flame lengths predicted due to climate change will hasten their uselessness. This will increasingly become more apparent when hardwood forests begins to burn more readily as climate change intensifies. The ability to effectively contain and fight forest fire needs to be strengthened, firstly, by equipping the DoFPS, and related fire fighting partner agencies, with a basic set of fire fighting equipment.

In the suppression of forest fires, the biggest risk is often the health and safety of firefighters. In the absence of proper firefighting equipment and PPE, personnel on fire incidents are exposed to life-threatening risks, and end up becoming more of a liability, than a help. During any fire incident, the health and safety of firefighters should remain the foremost concern. Therefore, PPE is a mandatory requirement as per the SOP developed by DoFPS for all firefighters. Furthermore, the SOP has listed equipment required for Rapid Response Teams (RRTs or first responders) and for group responders from various agencies in the IFFCG. A basic set of equipment required is provide in Table 16. The DoFPS should secure budget to procure adequate stock to be distributed across DoFPS once every five years, coinciding with the beginning of the Government's five-year planning period. Five year requirements should be estimated based on a stock take and needs assessment review conducted prior to the end of a five-year plan period.

Table 17. PPE, RRT and Group Equipment Requirement

No	Individual PPE	No	RRT Equipment	No	Group Equipment
1	Fire mask	1	Shovel	1	Communication sets
2	Fire gloves	2	Flappers	2	Rakes
3	Safety goggles	3	Rake	3	Shovels
4	Whistle	4	Spade	4	Pulaskis
5	Safety helmet	5	McLeod	5	Flappers
6	Torch	6	Water Bag	6	Power chainsaw
7	Water bottle	7	Drip torch	7	Water bags
8	Machete (Patang)	8	Portable water pump	8	McLeods
9	Safety rope (4m)	9	Collapsible water tank	9	Portable water pump
10	Backpack	10	Safety ropes (100m)	10	Collapsible tank
				11	Drone (UAV)
				12	Safety rope (100m)

As indicated in the IFFCG SOP, firefighters will need to be organized in crews that are trained in the use of the hand tools mentioned in Table 16.

Given the steep terrain across which most fires occur, the DoFPS has recognized that many of the standard firefighting equipment are either too cumbersome to carry or has proven ineffective under Bhutanese conditions. In addition to the basic list of equipment mentioned under Table 16, we recommend, in line

with suggestions made by the DoFPS, that equipment be locally improvised and made, to suit local conditions. A set of fire suppression hand tools appropriate for Bhutan by region or fuel-type should be designed and developed to supplement the basic set specified in Table 16.

For example, in Thimphu, swatters have been created by the Forest Fire Section of the FPED, DoFPS. These combine a 1-meter-long bamboo handle 2.5 to 3.5 cm thick with a swatting head made of 2 pieces of 40 cm wide unserviceable cotton jacket fire hose held together with brass screws and nuts. The hose head is held to the handle with a hose clamp. These have been found to be comparatively lightweight, easier to handle, and therefore more effective than using just tree branches.

From field experiences gathered by DoFPS and other firefighting agencies, water backpack pumps are found to be extremely effective, especially on grass fires or when the intensity is not so high. Often, after containing the fire, there are many instances of re-ignition since mop-up is done without using water. In such cases, wide use of water backpack pumps should be made part of the SOP for containing forest fires.

6.5.2 Implement an Advance Warning Systems

To facilitate faster response times and also to minimize risks to humans and property, a daily fire forecasting system based on weather forecasts should be developed and made readily available by region. Such a system should be tied into warning systems which are already being rolled out and implemented by the National Center for Hydro-meteorology (NCHM).

6.5.3 Strengthen Support for Large Fires

The IFFCG SOP requires backup resource and personnel planning for incidents that cannot be contained by the RRT's and may extend for days. However, organized "support function" to aid these suppression forces (operations) on large fires, especially in terms of providing drinking water, food, and, at times, sleeping accommodations on an extended incident is often difficult to make happen. Fires will become larger as the climate warms. In addition, the duration of large fires will increase. Fire suppression on a single fire may take weeks, not just a few days, as the climate warms. This increase in forest fire size and duration has already been seen in the United States, Australia, Africa, South America, and Indonesia.

A national fire cache should be developed to provide tents, sleeping bags, food, and tools for large, long-duration fires. The DoFS should identify, build, and manage about two to three such caches at strategic locations to ensure coverage of all Bhutan and effectively manage and control large fires.

6.5.4 Strengthen Communication Systems

In times of forest fires or any other disasters, access to quick communication is a must for effective first response, as well as managing situations, which lasts for days. Currently, the DoFPS maintains a radio communication network that connects its offices throughout the country on dedicated communication frequencies.

The DoFPS should map out strategic locations for additional relay stations, and estimate budget requirements for installation, and purchase of additional walkie-talkie sets to upscale the current communication system.

6.5.5 Strengthen the Interagency Forest Fire Coordinating Group (IFFCG)

Until 2017, forest firefighting was primarily the responsibility of the DoFPS and its field offices. Other participating agencies during suppression, like the Armed Forces (Royal Bhutan Army, Royal Bhutan Police, Royal Body Guards), fire volunteers, and local villagers were coordinated by the DoFPS. While the Department of Disaster Management (DDM) is the focal agency and leads all efforts related to disasters, the DoFPS has been given the mandate to manage forest fires from smaller incidents to disaster level incidents. Since 2005, the DoFPS in collaboration with the USDA Forest Service and with support from Conifer Research and Training Partnership (CORET) Project and USAID has initiated the institution of the Incident Command System (ICS) for forest fire as well as disaster response in Bhutan. Since then, numerous coordination protocols has been applied and tested under the general principles of ICS by both the DoFPS and DDM.

In 2017, under Royal Command to strengthen inter-agency coordination and to ensure firefighter safety during incidents, an Interagency Forest Fire Coordination Group (IFFCG) was formed for Thimphu Dzongkhag. This is also in line with the provisions of Forest Fire Management Strategy for Bhutan, 2013 to develop operational plans at various levels to define structures and assign responsibilities. The objectives for the group are:

1. To ensure the safety of firefighting personnel during forest fire incidents.
2. To provide for timely, efficient, and effective firefighting action on forest fire incidents.
3. To enhance better coordination among the different stakeholders involved in forest firefighting.
4. To achieve cost-effective and optimal resource distribution for all forest fire fighters.

The IFFCG is comprised of members from DoFPS, RBA, RBP, Desuung, Dzongkhag and DDM and acts as the Incident Commanders for respective agencies during fire incidents. All coordination, direction of crew, backup despatch, resource supply and post fire efforts are directed through the IFFCG. The IFFCG was found to be highly effective, especially in lead time on first incident response and for suppression coordination. Figure 11 below shows the coordination structure.

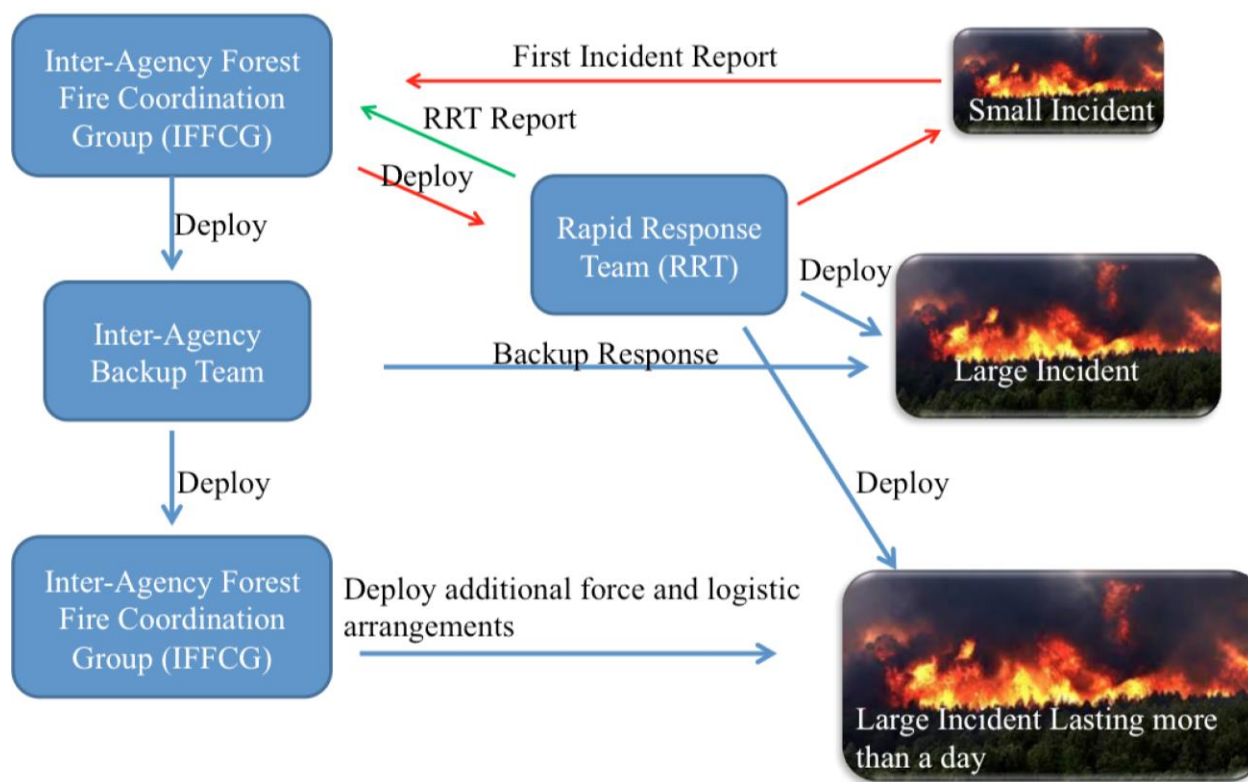


Figure 11. Operational procedure and coordination structure of the IFFCG.

The IFFCG has since then been institutionalized in all fire prone Dzongkhags of Haa, Paro, Thimphu, Wangdue, Bumthang, Mongar, Lhuntse, Trashigang and Trashiyangtse.

Immediate support should be provided to form and formalize the IFFCG in hitherto uncovered Dzongkhags. Priority should be placed on instituting the IFFCG in Dagana, Chukha and Tsirang, where fire incidences, although not currently high, are projected to increase. Once formalized in all Dzongkhags, the IFFCG mechanism should be replicated at the Gewog level with the highest fire risks (See Table 15).

6.5.6 Integrate Dzongkhag and Local Level Forest Fire Management Plans

To strengthen community involvement, devolve responsibilities to the local level, and streamline coordination on forest fire management activities, the DoFPS has already initiated formulation of Dzongkhag and Gewog Level Fire Management Plans under funding from the previous NAP Project. The piloting of plan development at both levels has been successfully completed and such plans have already been developed for some fire prone Dzongkhags. However, due to lack of funding support, focused implementation is still lacking. There are also other Gewog level forest plans like that LFMP that is recently being implemented by the DoFPS.

All local level plans should be integrated so that resource management as well as fire protection objectives are achieved in a holistic and coherent manner. More importantly, consistent budgetary support needs to be ensured to successfully implement these plans.

6.5.7 Strengthen Legislation

The management of forest fire is one of the most complex tasks involving a large number of stakeholders, therefore sensitization and information sharing regarding the subject is not always enough; it is also necessary to enforce legislation. The applications of legally bidding instruments should also be coupled with preventive measures to regulate human interventions in the forest or its periphery (agricultural work, picnic, constructions in the forest etc) which will ultimately help to reduce the risks of fire ignitions and spreads.

In the Bhutanese context, the Constitution of Bhutan 2008, specifically Chapter V, provides overarching protection responsibilities by promulgating that “every Bhutanese is a trustee of the Kingdom’s natural resources for the benefit of present and future generations and it is the fundamental duty of every citizen to contribute to the protection of the natural environment, conservation, and rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual, and physical pollution through the adoption and support of environment friendly practices”. The Constitution also mandates that 60% of forest cover be maintained for perpetuity, and that the government has the specific responsibility to preserve, conserve, and improve the environment; prevent pollution; secure ecologically balanced sustainable development; and enable a safe and healthy environment. Furthermore, the Forest and Nature Conservation Rules 2017 Chapter XI adequately covers various aspects of forest fire management inside the forests as well as in other land uses. Other relevant legal instrument that could be activated to enforce preventive measures against the forest fire are the National Environment Protection Act 2007 and the Disaster Management Act of Bhutan 2013.

A summary of legal documents that provide preventive, strategic, and regulatory tools to support forest fire prevention is shown in Table 17.

Table 18. Legislation, policy tools and frameworks to prevent and manage forest fires

What	Enactment Year	Pertinent Principles	Relevant Chapters	Implementing Agency
Constitution of Kingdom of Bhutan	2008	Provides overarching protection of Bhutan’s ecosystem. Describes the “... fundamental duty of every citizen to contribute to the protection of the natural environment, conservation, and rich biodiversity of Bhutan and mandates that 60% of forest cover be maintained for perpetuity”	Chapter 5	RGoB
Forest and Nature Conservation Act of Bhutan (FNCA)	1995	Provides the legal basis for protection, conservation, and sustainable use of forest resources. Allows for organizational set up at local level to prevent forest fires, impose penalties, and restore burnt areas.	Chapter 8, Article 31	MoAF

Forest and Nature Conservation Rules of Bhutan	2017 amended from twice (2006, 2012)	Derived from the FNCA (1995) and provides detailed guidelines on forest fire mitigation and management.	Chapter XI	MoAF
National Environment Protection Act of Bhutan (NEPA)	2007	Provides the legal basis for the conservation and protection of the environment.	Chapter V and Chapter VII	NEC
Environmental Assessment Act of Bhutan (EEA)	2000	Specifies regulation and procedures for EIAs	All chapters	NEC
Disaster Management Act of Bhutan (DMA)	2013	Provides the legal basis to ensure the protection of lives and properties by reducing and managing risk arising out of disasters. Specifies mechanisms for structural and financial aid during disasters.	All Chapters	MoHCA
Disaster Management Rules and Regulations of Bhutan	2014	Derivatives of DMA 2013	All Chapters	MoHCA
National Disaster Risk Management Framework	Recent	Calls for mainstreaming of disaster risk into national plans and policies.	Chapter 2, Section 2.1	Disaster Management Division
Interagency Forest Fire Coordinating Group (IFFCG)	2017	Stipulates frameworks for inter-agency coordination and SOPs for responding to forest fires.	All Chapters	DoFPS

Extant legal arrangements and provisions should be reviewed and revised to make them more effective.

6.6 Strengthen Research and Education

6.6.1 Forest Stand Related Information Collection

For successful predictive modeling or implementation of any fuel management regime, current understanding of forest stand, structure and available fuel will be crucial. Many of these parameters are already included in the National Forest Inventory data collection protocol. Any parameter that is missing in the NFI list but is essential for fuel modeling and management should be reviewed and inserted in the design. Such parameter may include:

- At canopy level: canopy cover, DBH, tree height, canopy tree height
- At understory level (live fuels): shrub and herbaceous cover and height

- At understory level (dead fuels): litter and fine woody debris (1h, 10h, and 100h) load
- Physiognomic characteristics of vegetation - evergreen versus deciduous, angiosperm versus gymnosperm forests.

6.6.2 General Information and Research Needs

The following information and research needs should be addressed as a priority.

- Collate accurate GIS based mapping of village locations, values-at-risk (historic religious sites), water sources, landfill sites, and roads.
- Develop, maintain and manage a forest fire database which stores and analyses information on:
 - Causes of forest fire (cause, date, location and weather conditions). A fire-cause investigation training program will be needed to fill this information accurately into the database.
 - Post-fire statistics based on the MTBS system adopted by the US Forest Service
- Research on the fire ecology of important forest types in Bhutan should be immediately initiated. Parameters related to post-fire fuel recovery, vegetation development, incidences and spread of pests and diseases, and species diversity should be studied. This work should inform the development of controlled burning prescriptions and techniques in forest fuels by forest type.
- Given the projected increased risks, a monitoring program to track flammability of broadleaved and mixed conifer forests should be rolled out.

6.6.3 Capacity Building of Fire Fighters

There is urgent need to educate personnel at all levels that “safety of firefighters always comes first and foremost”. The current IFFCG SOP should be reviewed based on field implementation and safety protocol and standards should be further refined to ensure health and safety of frontline firefighters. This will be particularly important given that forest fire intensity and flame lengths are predicted to increase significantly.

The capacity of firefighters to size up a incident and apply appropriate suppression techniques is key to effective suppression of fires and also determines the safety of firefighters. For example, in the US, for any person to be on an active fire incident, s/he must possess a “red card”, which is only given to those who have undergone basic firefighting and other requisite course. The type and level of courses that one takes determine the type of crew the firefighter operates on. In Bhutan, such qualification or training is not implicated for a person to be on an active incident. Farmers, volunteers, and many others join fire suppressors in efforts to put out the fire. Under such a scenario, while it helps to have larger suppression forces, safety is often compromised. Under future predicted scenarios, such lack of safety, could result in fatalities. Therefore, proper training and provision of safety equipment will be important.

As per the IFFCG SOP, the responsibility to train forestry and other personnel involved in firefighting is vested with the DoFPS. These include IFFCG Members (DoFPS, RBA, RBP, Desuung, Dzongkhag, DDM) and communities.

The DoFPS should schedule and rollout a multi-year training program covering the following topics:

- Incident management system and coordination
- Equipment handling (including handling of drones, power chainsaws, communication sets, GPS)
- Safety procedures and first aid
- Prescribed burn techniques based on prescribed burn plans
- Smoke jumpers in coordination with the DDM and Royal Bhutan Helicopter Services for first response in areas where there is no/limited access.

While training in basic firefighting can be given by foresters from DoFPS, there is need for external inputs in conducting advanced trainings on suppression as well as in conducting prescribed burns. A critical mass of national trainers should be built through a ‘training of trainers’ program with inputs from an external expert. Subsequent mass trainings can then be effectively imparted by national trainers.

6.6.4 Targeted Sensitization

The DoFPS should upscale and continue to sensitize and inform the public before and during the fire season. Sensitization programs should cover topics related to the impacts of fire and the need to exercise caution during the dry season, when accidental fires are most likely. Rather than being authoritative, messages should be geared at increasing public appreciation for the multiple benefits of forests (timber and non-timber resources, fodder, medicines, public recreation, aesthetics), and economic and ecological costs of unnecessary fires.

The following target groups need to be continually sensitized and engaged:

- School going children and teenagers
- Local government officials (Gups and Tshogpas)
- Community forest management groups
- Companies and organization who work in or close to forests

The DoFPS may consider developing a fire prevention mascot, such as Smokey Bear, used in the US, which has been overwhelmingly effective in reducing fires caused by miscreants.

Chapter VII: Conclusions

Recent events such as the mega fires in Australia and the US, and the fires now raging across Greece and Turkey, leave us in no doubt that rising temperatures will put at risk increasing large swathes of forests across the globe. Of particular concern is the fact that many recent fires have burned ecosystems where fire has historically been rare or absent.

Our findings which project increasing fire risks under a warming climate align closely with unfolding fire events globally, and warn us, of what may be in store, should we fail to proactively adapt to climate change. Failure to adapt and curtail the risks of future forest fires will entail significant economic and ecological costs for Bhutan. In addition to exacerbated loss of property and rapid disruptions to ecosystems and loss of biodiversity, increased and intensive forest fires will significantly contribute to Bhutan's carbon emissions, thereby – possibly – compromising, Bhutan's carbon neutral status. The consequences of a failure to adapt will be hugely disastrous for Bhutan.

Our predictions are however estimated based on climate change scenarios. It has to be noted that there is considerable uncertainty as to the actual weather Bhutan will experience, as we transition into the future. Critical uncertainties relate to the frequency and severity of drought cycles associated with teleconnections with ocean-atmosphere circulation patterns. Relative humidity and wind speed are also major drivers of fire behavior. The seasonal and diurnal patterns of these critical fire weather variables remain highly uncertain into the foreseeable future. Thus, future fire behavior is fraught with uncertainty and modeling future fire potential requires making science-based projections of future climate. Yet, the uncertainty of future weather should not paralyze action.

As of now, Bhutan has made no significant long-term financial investment in forest fire management, beyond covering the cost of the DoFPS fire management staff. Given that projected risks are considerable across all forest types, it is imperative that substantive investment be secured to implement a dynamic and proactive fire mitigation and adaptation program. Such an investment will pay itself out in the form reduced carbon emissions, protected infrastructure, and conserved biodiversity.

Given that climate/weather and terrain are beyond the scope of management to alter, climate response needs to focus proactively on managing the two remaining fire risk factors: forest fuels and human behavior. The proper management of forest fuels, people's attitudes towards fire prevention, and the efficacy of response systems, will determine fire's impact on Bhutan under future climates. It is in this regard that we recommend a robust set of adaptive management strategies coupled with continuing focus on awareness building and community engagement to effectively mitigate and adapt to forest fire in Bhutan.

Annexures

Annex 1. Gewogs at risk under chir pine forest

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Athang	118	117
Daga	81	81
Saleng	66	66
Patala	37	37
Udzorong	34	34
Shumer	31	31
Drepung	25	25
Narang	25	25
Kengkhar	25	25
Ruepisa	23	23
Yangnyer	23	23
Tsamang	19	19
Bartsham	19	19
Thangrong	19	19
Chhubu	18	18
Lajab	18	18
Mongar	17	17
Chaskhar	14	14
Tsenkhar	14	14
Menbi	14	14
Jaray	13	13
Bidung	12	12
Langthil	12	12
Khoma	11	11
Ramjar	11	11
Yalang	11	11
Dzoma	10	10
Jamkhar	9	9
Lingmukha	9	9
Drametse	8	8
Guma	8	8
Samkhar	7	7
Ngatshang	7	7
Kanglung	7	7
Jurmey	7	7

Metsho	7	7
Gangzur	7	7
Tsakaling	7	7
Chhali	7	7
Toewang	7	7
Thedtsho	7	6
Chhimung	6	6
Phangyuel	6	6
Korphu	6	6
Nahi	5	5
Bapisa	5	5
Minjay	5	5
Lauri	5	5
Nangkor	5	5
Nyisho	5	5
Gasetsho Gom	4	4
Gasetsho Om	4	4
Talo	4	4
Trong	4	4
Nanong	4	4
Toepisa	3	3
Tomzhangtshen	3	3
Shermung	3	3
Balam	2	2
Phongme	2	2
Kabjisa	2	2
Shingkhar	2	2
Khaling	2	2
Kangpara	2	2
Shengabjimi	1	1
Khamdang	1	1
Bjena	1	1
Tsangkha	1	1
Bardo	1	1
Tangsibji	1	1
Gongdue	1	1
Dungmin	1	1
Toetsho	1	1
Shongphu	1	1

Annex 2. Gewogs at risk under blue pine forests

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Mewang	69	68
Kawang	57	56
Chhoekhor	50	49
Naja	41	41
Chhume	41	40
Chang	39	38
Tsento	37	37
Tang	37	36
Doga	28	27
Chapchha	25	25
Sama	22	21
Doteng	20	19
Shapa	18	18
Lungnyi	18	17
Uesu	16	15
Bji	14	14
Ura	14	14
Lamgong	12	12
Dagala	7	7
Dopshari	7	7
Dungna	6	6
Genye	6	6
Katsho	5	5
Ruepisa	5	5
Tangsibji	5	5
Geling	5	5
Hungrel	4	4
Gangte	4	4
Wangchang	4	4
Sephu	3	3
Bjena	3	3
Trashiyangtse	3	3
Phobji	2	2
Metap	1	1

Annex 3. Gewogs at risk under mixed conifer forests

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
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Kazhi	49	54
Lunana	48	53
Langthil	35	36
Athang	35	36
Kurtoe	32	37
Bumdeling	31	34
Tseza	31	31
Toewang	28	30
Nubi	27	28
Merak	26	26
Sephu	25	27
Gangzur	24	27
Khoma	23	24
Tangsibji	20	21
Tsento	20	22
Chhoekhor	18	20
Korphu	17	17
Sombey	17	17
Sakteng	16	18
Goenkhatoe	16	18
Dangchhu	16	16
Kangpara	15	15
Kawang	15	16
Bji	13	15
Dagala	11	13
Laya	11	13
Kabjisa	11	11
Nangkor	11	11
Chhume	11	12
Goenkham	10	11
Minjay	10	10
Doteng	10	10
Sama	8	9
Ura	8	8
Tang	8	8
Bjachho	8	8
Lauri	7	7
Chapchha	7	8
Gasetsho Om	7	7
Gakiling	6	6
Trashiyangtse	6	6

Phobji	5	7
Shermung	5	5
Shingkhar	5	5
Bongo	5	5
Metsho	5	5
Jigmichhoeling	5	5
Mewang	4	5
Saleng	4	4
Bara	4	4
Ruepisa	4	4
Jaray	4	4
Daga	4	4
Genye	4	4
Dungna	4	4
Bjena	4	4
Gangte	4	4
Khaling	4	4
Nyisho	4	4
Phuentenchhu	3	3
Uesu	3	4
Metap	3	3
Nahi	3	3
Naja	3	3
Toepisa	3	3
Chang	3	3
Naro	3	4
Tsenkhar	2	2
Shongphu	2	2
Phongme	2	2
Doga	2	2
Getana	2	1
Yalang	1	2
Trong	1	1
Tsakaling	1	1
Geling	1	1
Katsho	1	1
Goenshari	1	1
Tsamang	1	1
Lingzhi	1	2
Lungnyi	1	1
Lamgong	1	1

Chhubu	1	1
Shapa	1	1
Menbi	1	1
Jamkhar	1	1
Serthig	1	0

Annex 4. Gewogs at risk under fir forests

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Chhoechor	78	94
Lunana	66	73
Sephu	65	72
Tang	63	67
Kazhi	56	63
Bumdeling	56	58
Sakteng	55	56
Bji	53	58
Laya	52	62
Kurtoe	51	58
Merak	45	46
Khoma	44	48
Nubi	39	41
Tsento	35	39
Ura	29	29
Toewang	28	29
Goenkhatoe	26	28
Chhume	24	26
Dagala	24	26
Tangsibji	22	26
Sama	18	19
Athang	18	19
Doteng	17	18
Gangzur	17	17
Saleng	15	14
Gasetsho Om	13	13
Lingzhi	11	14
Kawang	11	12
Dangchhu	10	11
Nangkor	9	8
Tseza	8	8
Kangpara	8	8

Naro	8	10
Sombey	8	8
Goenkhamé	7	8
Mewang	6	6
Trashiyangtse	5	5
Chang	4	4
Langthil	4	5
Shingkhar	4	4
Korphu	4	4
Shermung	3	3
Metsho	3	3
Chapchha	3	4
Kabjisa	3	3
Genye	3	3
Minjay	3	3
Bongo	3	3
Daga	3	3
Lauri	3	3
Jaray	2	2
Bjachho	2	2
Phobji	2	2
Jigmichhoeling	2	2
Shongphu	2	2
Nyisho	2	2
Dragteng	2	2
Gakiling	1	1
Naja	1	1
Tsamang	1	1
Uesu	1	1
Phongme	1	1
Katsho	1	1
Phuentenchhu	1	1
Goenshari	1	1
Soe	1	1
Gangte	1	1
Tsenkhar	1	1
Yalang	1	1
Khaling	1	1
Lungnyi	1	0

Annex 5. Gewogs at risk under broadleaved forests below 2000 masl

Gewog	RCP 4.5 (km ²)	RCP 8.5 (km ²)
Pangkhar	460	457
Athang	292	294
Jigmichhoeling	288	286
Trong	259	258
Saleng	219	218
Bongo	209	208
Nangkor	202	201
Serthig	199	198
Ngangla	187	186
Bjoka	176	175
Langchhenphu	175	173
Daga	167	166
Senge	165	162
Dewathang	159	158
Langthil	159	160
Martshala	158	157
Gongdue	157	156
Chhoekhor	147	165
Beteni	139	138
Doban	136	135
Jangchhubling	136	135
Korphu	133	133
Bardo	130	130
Sombey	127	128
Norbugang	123	122
Shingkhar	122	122
Dechhenling	119	118
Nichula	118	117
Lunana	115	128
Getana	113	112
Hiley	111	111
Chokhorling	111	110
Kazhi	109	121
Gakiling	108	108
Tang	108	112
Toewang	104	106
Gangzur	103	106
Kurtoe	103	114

Dala	102	102
Khar	98	98
Khoma	98	103
Dungmin	97	97
Phuentsholing	96	96
Bumdeling	95	101
Sephu	94	104
Tseza	94	94
Tsento	93	100
Geling	93	92
Lauri	92	91
Phuntsthothang	90	89
Kalidzingkha	89	88
Dorona	88	87
Gozhing	87	87
Merak	85	86
Samtse	84	83
Kawang	83	84
Umling	82	82
Bji	82	88
Taklai	81	80
Mewang	81	80
Lhamoizingkha	81	80
Patalay	80	80
Tangsibji	79	84
Dekiling	78	77
Tsamang	77	77
Udzorong	77	77
Sakteng	77	79
Chhume	76	78
Tsendagang	76	75
Pagli	74	73
Kengkhar	73	73
Shumer	73	73
Tading	72	72
Nubi	71	74
Deorali	70	70
Dorokha	70	70
Silambi	69	69
Dungna	67	66
Chengmari	65	64
Bara	64	64

Laya	64	76
Namgyel Chhoeling	64	63
Lajab	63	62
Kangpara	62	62
Sherzhong	62	61
Denchhukha	59	58
Lumang	58	58
Phuentenchhu	57	57
Logchina	54	54
Pemathang	54	53
Wangphu	53	53
Nanong	53	53
Ura	52	51
Samphelling	51	51
Khipisa	50	50
Shermung	49	49
Sama	49	50
Chhimung	48	48
Doteng	47	48
Gomdar	47	47
Tendu	47	47
Jurmey	47	47
Chang	46	45
Naja	46	46
Ruepisa	46	45
Thangrong	45	45
Metsho	45	45
Zobel	45	44
Goenkhatoe	43	46
Dagala	43	46
Gasetsho Om	41	42
Khaling	40	40
Kabjisa	40	40
Jaray	39	39
Trashiyangtse	38	38
Minjay	37	37
Chapchha	36	36
Drepung	34	34
Chhubu	34	34
Biru	34	34
Samrang	34	33
Dungtoe	33	33

Mongar	33	33
Narang	33	33
Bhur	33	33
Yangnyer	33	33
Samkhar	32	32
Ngatshang	32	32
Gesarling	32	32
Drugyelgang	32	32
Doga	31	30
Tsenkhar	30	30
Trashiding	30	30
Bjachho	29	29
Metap	28	28
Gelephu	28	27
Yalang	27	28
Thrimshing	27	27
Kanglung	27	27
Chongshing	27	27
Chaskhar	27	27
Tsakaling	27	27
Tsangkha	26	26
Dangchhu	26	27
Goenkhamé	25	25
Yurung	24	24
Goenshari	24	24
Menbi	24	24
Tsirangtoe	23	23
Jamkhar	22	21
Chargharay	21	21
Phongme	21	21
Shongphu	21	21
Dunglegang	21	21
Uesu	20	20
Bartsham	20	20
Shapa	20	20
Lungnyi	20	19
Bjena	18	19
Rangthangling	17	17
Barzhong	17	17
Nyisho	16	16
Toepisa	15	14
Bidung	14	14

Dragteng	14	14
Lamgong	14	13
Chhali	13	13
Nahi	13	13
Ramjar	13	13
Guma	13	13
Lingzhi	13	16
Genye	13	13
Tomzhangtshen	12	12
Dzoma	12	12
Drametse	12	12
Gozhi	12	12
Shompangkha	11	11
Naro	11	14
Lingmukha	10	10
Phobji	10	11
Ugentse	9	9
Yoeseltse	9	9
Phangyuel	9	9
Balam	9	9
Gangte	8	9
Shemjong	8	8
Thedtsho	8	8
Talo	8	8
Toetsho	8	8
Mendrelgang	8	8
Khamdang	8	8
Katsho	7	8
Gasetsho Gom	7	7
Dopshari	7	7
Bapisa	7	7
Shengabjimi	7	7
Tsholingkhon	7	7
Kikorthang	6	6
Gosarling	5	5
Sipsu	5	5
Radi	5	5
Hungrel	4	4
Wangchang	4	4
Soe	1	1
Chhuzagang	1	1

Annex 6. Total households at increased fire risk by Gewogs in Chir pine forests under RCP 4.5 from now till 2050

Gewog	Dzongkhag	Households
Bartsham	Trashigang	112
Bidung	Trashigang	110
Daga	Wangduephodrang	91
Ruepisa	Wangduephodrang	74
Balam	Monggar	62
Saleng	Monggar	62
Udzorong	Trashigang	59
Nyisho	Wangduephodrang	58
Chaskhar	Monggar	56
Guma	Punakha	52
Chhubu	Punakha	50
Bapisa	Punakha	46
Jamkhar	Yangtse	44
Athang	Wangduephodrang	42
Menbi	Lhuentse	40
Mongar	Monggar	39
Gangzur	Lhuentse	33
Ramjar	Yangtse	33
Thedtsho	Wangduephodrang	33
Tsenkhar	Lhuentse	33
Samkhar	Trashigang	31
Drepung	Monggar	30
Kanglung	Trashigang	29
Phangyuel	Wangduephodrang	29
Narang	Monggar	28
Chhali	Monggar	25
Gasetsho Gom	Wangduephodrang	25
Patalay	Tsirang	25
Yangnyer	Trashigang	25
Dzoma	Punakha	23
Thangrong	Monggar	23
Lajab	Dagana	19
Nahi	Wangduephodrang	19
Kabjisa	Punakha	17
Khoma	Lhuentse	17
Tsamang	Monggar	17
Minjay	Lhuentse	16

Bjena	Wangduephodrang	15
Shermung	Monggar	15
Lingmukha	Punakha	14
Gasetsho Om	Wangduephodrang	13
Yalang	Yangtse	13
Tsakaling	Monggar	12
Ngatshang	Monggar	11
Radi	Trashigang	11
Jaray	Lhuentse	9
Metsho	Lhuentse	8
Phongme	Trashigang	8
Talo	Punakha	8
Drametse	Monggar	7
Khamdang	Yangtse	7
Shongphu	Trashigang	7
Toepisa	Punakha	7
Jurmey	Monggar	6
Nanong	Pema Gatshel	6
Shengabjimi	Punakha	6
Shumer	Pema Gatshel	6
Toewang	Punakha	6
Tomzhangtshen	Yangtse	5
Tsangkha	Dagana	4
Kangpara	Trashigang	3
Trong	Zhemgang	3
Bardo	Zhemgang	2
Langthil	Trongsa	2
Kengkhar	Monggar	1
Lauri	Samdrup Jongkhar	1
Lumang	Trashigang	1
Shingkhar	Zhemgang	1
Thrimshing	Trashigang	1
Tsholingkor	Tsirang	1

Annex 7. Total households at increased fire risk in Blue pine forests by Gewogs under RCP 4.5 from now till 2050

Gewog	Dzongkhag	Households
Kawang	Thimphu	108
Chhoekhor	Bumthang	54

Chang	Thimphu	44
Chapchha	Chhukha	43
Naja	Paro	38
Tsento	Paro	38
Mewang	Thimphu	26
Uesu	Haa	22
Tang	Bumthang	21
Gangte	Wangduephodrang	19
Sama	Haa	19
Dopshari	Paro	18
Ruepisa	Wangduephodrang	18
Shapa	Paro	15
Bjena	Wangduephodrang	14
Sephu	Wangduephodrang	14
Doga	Paro	12
Chhume	Bumthang	10
Genye	Thimphu	10
Wangchang	Paro	10
Lamgong	Paro	7
Doteng	Paro	6
Lungnyi	Paro	6
Dagala	Thimphu	5
Hungrel	Paro	5
Bji	Haa	4
Katsho	Haa	4
Trashiyangtse	Yangtse	2
Bji	Haa	1
Dungna	Chhukha	1
Geling	Chhukha	1
Phobji	Wangduephodrang	1
Tangsibji	Trongsa	1
Ura	Bumthang	1

Annex 8. Total households at increased fire risk in broadleaved forests (<2000) by Gewogs under RCP 4.5 from now till 2050

Gewog	Dzongkhag	Households
Jigmichhoeling	Sarpang	408
Hiley	Sarpang	395
Bongo	Chhukha	373

Phuentsholing	Chhukha	373
Dala	Chhukha	362
Tading	Samtse	362
Doban	Sarpang	304
Nanong	Pema Gatshel	301
Shumer	Pema Gatshel	292
Dewathang	Samdrup Jongkhar	278
Pagli	Samtse	262
Samphelling	Chhukha	255
Dorokha	Samtse	238
Trong	Zhemgang	214
Gozhi	Dagana	210
Chongshing	Pema Gatshel	202
Lumang	Trashigang	195
Trashiding	Dagana	194
Shongphu	Trashigang	192
Biru	Samtse	179
Zobel	Pema Gatshel	178
Kalidzingkha	Dagana	175
Gesarling	Dagana	174
Geling	Chhukha	172
Bara	Samtse	170
Drugyelgang	Dagana	170
Bardo	Zhemgang	168
Dechhenling	Pema Gatshel	166
Shingkhar	Zhemgang	165
Norbugang	Pema Gatshel	156
Denchhukha	Samtse	154
Tsangkha	Dagana	153
Dekiling	Sarpang	149
Langthil	Trongsa	149
Lhamoizingkha	Dagana	149
Lajab	Dagana	141
Tsendagang	Dagana	139
Korphu	Trongsa	134
Ngangla	Zhemgang	130
Bjachho	Chhukha	127
Jangchhubling	Samdrup Jongkhar	127
Chokhorling	Pema Gatshel	126
Gasetsho Om	Wangduephodrang	125
Dungtoe	Samtse	124

Tendu	Samtse	117
Samtse	Samtse	114
Shompangkha	Sarpang	112
Namgyel Chhoeling	Samtse	110
Nangkor	Zhemgang	108
Yurung	Pema Gatshel	108
Lauri	Samdrup Jongkhar	104
Kengkhar	Monggar	103
Jurmey	Monggar	102
Daga	Wangduephodrang	101
Martshala	Samdrup Jongkhar	101
Mongar	Monggar	98
Bjena	Wangduephodrang	97
Chhimung	Pema Gatshel	94
Kabjisa	Punakha	94
Gozhing	Zhemgang	89
Udzorong	Trashigang	84
Kangpara	Trashigang	81
Dorona	Dagana	80
Logchina	Chhukha	80
Kikorthang	Tsirang	77
Pangkhar	Zhemgang	76
Gosarling	Tsirang	75
Serthig	Samdrup Jongkhar	73
Gomdar	Samdrup Jongkhar	72
Shermung	Monggar	68
Sherzhong	Sarpang	68
Dragteng	Trongsa	67
Gelephu	Sarpang	65
Gangzur	Lhuentse	64
Bhur	Sarpang	63
Phuntsthothang	Samdrup Jongkhar	62
Samkhar	Trashigang	62
Rangthangling	Tsirang	61
Sipsu	Samtse	61
Deorali	Dagana	58
Dungmin	Pema Gatshel	58
Thrimshing	Trashigang	58
Yalang	Yangtse	58
Chargharay	Samtse	57
Phuentenchhu	Tsirang	56

Chaskhar	Monggar	54
Getana	Chhukha	52
Ngatshang	Monggar	52
Kanglung	Trashigang	51
Ruepisa	Wangduephodrang	50
Dunglegang	Tsirang	49
Jamkhar	Yangtse	49
Khaling	Trashigang	49
Tangsibji	Trongsa	49
Yoeseltse	Samtse	49
Beteni	Tsirang	48
Mendrelgang	Tsirang	48
Langchhenphu	Samdrup Jongkhar	47
Yangnyer	Trashigang	47
Goenkhame	Gasa	46
Tsirangtoe	Tsirang	45
Wangphu	Samdrup Jongkhar	45
Khoma	Lhuentse	44
Phongme	Trashigang	43
Tsamang	Monggar	43
Bjoka	Zhemgang	42
Tseza	Dagana	42
Tsholingkor	Tsirang	42
Bumdeling	Yangtse	41
Chhali	Monggar	41
Barzhong	Tsirang	39
Minjay	Lhuentse	39
Pemathang	Samdrup Jongkhar	39
Radi	Trashigang	38
Patalay	Tsirang	37
Nyisho	Wangduephodrang	36
Toepisa	Punakha	35
Tomzhangtshen	Yangtse	35
Saleng	Monggar	34
Goenshari	Punakha	33
Senge	Sarpang	33
Shemjong	Tsirang	33
Ugentse	Samtse	32
Umling	Sarpang	32
Dungna	Chhukha	30
Khipisa	Dagana	29

Balam	Monggar	28
Kurtoe	Lhuentse	28
Bidung	Trashigang	27
Drepung	Monggar	27
Silambi	Monggar	27
Tsakaling	Monggar	27
Gasetsho Gom	Wangduephodrang	26
Sombey	Haa	26
Trashiyangtse	Yangtse	24
Metap	Chhukha	23
Metsho	Lhuentse	22
Thangrong	Monggar	22
Shengabjimi	Punakha	21
Toewang	Punakha	21
Chengmari	Samtse	19
Nahi	Wangduephodrang	19
Gongdue	Monggar	18
Jaray	Lhuentse	16
Phangyuel	Wangduephodrang	15
Toetsho	Yangtse	15
Khamdang	Yangtse	14
Khar	Pema Gatshe	14
Nichula	Dagana	13
Menbi	Lhuentse	12
Tsenkhar	Lhuentse	12
Nubi	Trongsa	11
Tsholingkhör	Tsirang	11
Chhubu	Punakha	9
Taklai	Sarpang	9
Talo	Punakha	9
Athang	Wangduephodrang	6
Chhuzagang	Sarpang	5
Gakiling	Haa	5
Kazhi	Wangduephodrang	5
Narang	Monggar	4
Bartsham	Trashigang	3
Guma	Punakha	3
Lingmukha	Punakha	3
Merak	Trashigang	3
Ramjar	Yangtse	3
Drametse	Monggar	2

Dzoma	Punakha	2
Dangchhu	Wangduephodrang	1
Samrang	Samdrup Jongkhar	1

Annex 9. Religious structures at risk by Gewogs under RCP 4.5 from now till 2050

Gewog	Dzongkhag	Number of Structures
Nangkor	Zhemgang	13
Shongphu	Trashigang	12
Chhoekhor	Bumthang	10
Shermung	Monggar	10
Yurung	Pema Gatshel	10
Bardo	Zhemgang	10
Serthig	Samdrup Jongkhar	9
Zobel	Pema Gatshel	8
Kawang	Thimphu	8
Langthil	Trongsa	8
Trong	Zhemgang	8
Tang	Bumthang	7
Mewang	Thimphu	7
Thrimshing	Trashigang	7
Jurmey	Monggar	6
Kangpara	Trashigang	6
Phongme	Trashigang	6
Bjoka	Zhemgang	6
Shingkhar	Zhemgang	6
Khoma	Lhuentse	5
Doteng	Paro	5
Chongshing	Pema Gatshel	5
Dechhenling	Pema Gatshel	5
Nanong	Pema Gatshel	5
Bidung	Trashigang	5
Yangnyer	Trashigang	5
Korphu	Trongsa	5
Pangkhar	Zhemgang	5
Kalidzingkha	Dagana	4
Uesu	Haa	4
Gongdue	Monggar	4
Mongar	Monggar	4
Thangrong	Monggar	4
Naja	Paro	4

Dungmin	Pema Gatshel	4
Norbugang	Pema Gatshel	4
Dewathang	Samdrup Jongkhar	4
Gomdar	Samdrup Jongkhar	4
Lauri	Samdrup Jongkhar	4
Martshala	Samdrup Jongkhar	4
Samtse	Samtse	4
Bjena	Wangduephodrang	4
Gangte	Wangduephodrang	4
Bongo	Chhukha	3
Phuentsholing	Chhukha	3
Tseza	Dagana	3
Metsho	Lhuentse	3
Ngatshang	Monggar	3
Saleng	Monggar	3
Shermung	Monggar	3
Silambi	Monggar	3
Tsamang	Monggar	3
Doga	Paro	3
Hungrel	Paro	3
Tsento	Paro	3
Chhimung	Pema Gatshel	3
Chokhorling	Pema Gatshel	3
Shumer	Pema Gatshel	3
Chhubu	Punakha	3
Dzoma	Punakha	3
Talo	Punakha	3
Langchhenphu	Samdrup Jongkhar	3
Pagli	Samtse	3
Ugentse	Samtse	3
Chang	Thimphu	3
Radi	Trashigang	3
Udzorong	Trashigang	3
Yangnyer	Trashigang	3
Dragteng	Trongsa	3
Gasetsho Om	Wangduephodrang	3
Bumdeling	Yangtse	3
Yalang	Yangtse	3
Ngangla	Zhemgang	3
Chhume	Bumthang	2
Chapchha	Chhukha	2
Dala	Chhukha	2

Getana	Chhukha	2
Katsho	Haa	2
Sama	Haa	2
Sombey	Haa	2
Gangzur	Lhuentse	2
Jaray	Lhuentse	2
Khoma	Lhuentse	2
Kurtoe	Lhuentse	2
Menbi	Lhuentse	2
Tsenkhar	Lhuentse	2
Tsenkhar	Lhuentse	2
Chaskhar	Monggar	2
Chhali	Monggar	2
Drepung	Monggar	2
Tsakaling	Monggar	2
Dopshari	Paro	2
Lamgong	Paro	2
Lungnyi	Paro	2
Wangchang	Paro	2
Chongshing	Pema Gatshel	2
Khar	Pema Gatshel	2
Bapisa	Punakha	2
Chengmari	Samtse	2
Tendu	Samtse	2
Jigmichhoeling	Sarpang	2
Bartsham	Trashigang	2
Kanglung	Trashigang	2
Khaling	Trashigang	2
Samkhar	Trashigang	2
Samkhar	Trashigang	2
Langthil	Trongsa	2
Tangsibji	Trongsa	2
Athang	Wangduephodrang	2
Bjena	Wangduephodrang	2
Daga	Wangduephodrang	2
Nyisho	Wangduephodrang	2
Tomzhangtshen	Yangtse	2
Trashiyangtse	Yangtse	2
Gozhing	Zhemgang	2
Chhume	Bumthang	1
Bjachho	Chhukha	1
Geling	Chhukha	1

Geling	Chhukha	1
Samphelling	Chhukha	1
Samphelling	Chhukha	1
Drugyelgang	Dagana	1
Gesarling	Dagana	1
Laya	Gasa	1
Bji	Haa	1
Gakiling	Haa	1
Gangzur	Lhuentse	1
Jaray	Lhuentse	1
Kurtoe	Lhuentse	1
Menbi	Lhuentse	1
Minjay	Lhuentse	1
Tsenkhar	Lhuentse	1
Balam	Monggar	1
Chhali	Monggar	1
Drepung	Monggar	1
Jurmey	Monggar	1
Kengkhar	Monggar	1
Saleng	Monggar	1
Silambi	Monggar	1
Thangrong	Monggar	1
Tsakaling	Monggar	1
Tsamang	Monggar	1
Dopshari	Paro	1
Shapa	Paro	1
Chokhorling	Pema Gatshel	1
Nanong	Pema Gatshel	1
Guma	Punakha	1
Lingmukha	Punakha	1
Toepisa	Punakha	1
Gomdar	Samdrup Jongkhar	1
Lauri	Samdrup Jongkhar	1
Phuntsthothang	Samdrup Jongkhar	1
Wangphu	Samdrup Jongkhar	1
Bara	Samtse	1
Chargharay	Samtse	1
Dorokha	Samtse	1
Dungtoe	Samtse	1
Sherzhong	Sarpang	1
Sherzhong	Sarpang	1
Umling	Sarpang	1

Kawang	Thimphu	1
Kanglung	Trashigang	1
Khaling	Trashigang	1
Lumang	Trashigang	1
Merak	Trashigang	1
Samkhar	Trashigang	1
Udzorong	Trashigang	1
Dragteng	Trongsa	1
Tangsibji	Trongsa	1
Beteni	Tsirang	1
Kikorthang	Tsirang	1
Tsirangtoe	Tsirang	1
Daga	Wangduephodrang	1
Daga	Wangduephodrang	1
Gasetsho Gom	Wangduephodrang	1
Kazhi	Wangduephodrang	1
Nahi	Wangduephodrang	1
Phangyuel	Wangduephodrang	1
Ruepisa	Wangduephodrang	1
Sephu	Wangduephodrang	1
Thedtsho	Wangduephodrang	1
Thedtsho	Wangduephodrang	1
Bumdeling	Yangtse	1
Jamkhar	Yangtse	1
Jamkhar	Yangtse	1
Toetsho	Yangtse	1
Tomzhangtshen	Yangtse	1
Trashiyangtse	Yangtse	1
Yalang	Yangtse	1
Shingkhar	Zhemgang	1

Annex 10. Details of religious structures at risk by Gewogs and Dzongkhags

Name	Gewog	Dzongkhag	Category
Jarogang Lhakhang	Athang	Wangdue Phodrang	Lhakhang
Lophokha Lhakhang	Athang	Wangdue Phodrang	Lhakhang
Sanga Choekhorling Lhakhang	Baap	Punakha	Lhakhang
Dorangthang Peljorcholing Lhakhang	Baap	Punakha	Lhakhang
Khepshing Jigme Nidup Lhakhang	Balam	Mongar	Lhakhang
Beteni Lhakhang	Bara	Samtse	Lhakhang
Rawathang Lhakhang	Bardo	Zhemgang	Lhakhang
Phulabi Lhakhang	Bardo	Zhemgang	Lhakhang

Umling Lhakhang	Bardo	Zhemgang	Lhakhang
Langdurbi Lhakhang	Bardo	Zhemgang	Lhakhang
Digala Lhakhang	Bardo	Zhemgang	Lhakhang
Bardo Goenpapong Lhakhang	Bardo	Zhemgang	Lhakhang
Goenpong Ugyencholing Lhakhang	Bardo	Zhemgang	Lhakhang
Kalamti Lhakhang	Bardo	Zhemgang	Lhakhang
Relangbi Lhakhang	Bardo	Zhemgang	Lhakhang
Donga Moense Drajeling Gomdey	Bardo	Zhemgang	Gomdey
Muktangkhar Lhakhang	Bartsham	Trashigang	Gomdey
Kumung Lhakhang	Bartsham	Trashigang	Gomdey
Chorten	Bartsham	Trashigang	Chorten
Dhupi Dangra Mandir	Beteni	Tsirang	Mandhir
Lhendup Choling Lhakhang	Bidung	Trashigang	Gomdey
Gelong Goenpa Lhakhang	Bidung	Trashigang	Gomdey
Kherie Lhakhang	Bidung	Trashigang	Gomdey
Jaipo Lhakhang	Bidung	Trashigang	Gomdey
Mani dangray chorten	Bidung	Trashigang	Chorten
Zangdhog Pelri	Bjabcho	Chukha	Lhakhang
Drak Jangchub Lhakhang	Bjena	Wangdue Phodrang	Lhakhang
Khothang Jangsa Dzong	Bjena	Wangdue Phodrang	Lhakhang
Balakha Lhakhang	Bjena	Wangdue Phodrang	Lhakhang
Gangkalo Lhakhang	Bjena	Wangdue Phodrang	Lhakhang
Dungkhor Lhakhang	Bjena	Wangdue Phodrang	Lhakhang
Rinchhenling Lhakhang	Bjena	Wangdue Phodrang	Lhakhang
Tenchog Samten Choling	Bji	Ha	Choling
Gyen saer Lakhang	Bji	Ha	Lhakhang
Bjoka Trong Lhakhang	Bjoka	Zhemgang	Lhakhang
Barpong Lhakhang	Bjoka	Zhemgang	Lhakhang
Samdrupcholing Lhakhang	Bjoka	Zhemgang	Lhakhang
Dalibi Lhakhang	Bjoka	Zhemgang	Lhakhang
Kumari Lhakhang	Bjoka	Zhemgang	Lhakhang
Bazaguru Lhakhang	Bjoka	Zhemgang	Lhakhang
Meritsemo Lhakhang	Bongo	Chukha	Lhakhang
Bongo Lhakhang	Bongo	Chukha	Lhakhang
Gedu Lhakhang	Bongo	Chukha	Lhakhang
Ketokha Lhakhang	Bongo	Chukha	Lhakhang
Zhapang Lhakhang	Bumdeling	Trashiyangtse	Lhakhang
Phanteng Lhakhang	Bumdeling	Trashiyangtse	Lhakhang
Shangyul Lhakhang	Bumdeling	Trashiyangtse	Lhakhang
Nganteng Lhakhang	Bumdeling	Trashiyangtse	Lhakhang
Shapchi Dungkhor Lhakhang	Chali	Mongar	Lhakhang
Charshong Samten Choling Lhakhang	Chali	Mongar	Lhakhang

Tshamkhang Tshewang Jamtsho ye Lhakhang	Chali	Mongar	Lhakhang
Kuruzam Pemawogling Lhakhang	Chali	Mongar	Lhakhang
Tashigang Goenpa	Chang	Thimphu	Goenpa
Drupkhana Lhakhang	Chang	Thimphu	Lhakhang
Semtokha Dzong	Chang	Thimphu	Shedra
Gur Gonpa	Chapcha	Chukha	Goenpa
Karsang Lhakhang	Chapcha	Chukha	Lhakhang
Chargharey Dratsang	Chargharey	Samtse	Dratshang
Bar Dungkhor Lhakhang	Chaskar	Mongar	Lhakhang
Hatkholo_Bazar_Chorten	Chengmari	Samtse	Chorten
Hatkholo Shivalaya Mandir	Chengmari	Samtse	Shivalaya Mandir
Jiligang Lhakhang	Chhubu	Punakha	Lhakhang
Jangwakha Lhakhang	Chhubu	Punakha	Lhakhang
Bali Lhakhang	Chhubu	Punakha	Lhakhang
Sonamgatshel Nye	Chhubu	Punakha	Nye
Chimong Dechenpelri Lhakhang	Chimoong	Pema Gatshel	Lhakhang
Redingla Lhakhang	Chimoong	Pema Gatshel	Lhakhang
Longkholum Lhakhang	Chimoong	Pema Gatshel	Lhakhang
Nyaskhar Dungkhor	Chimoong	Pema Gatshel	Dungkhor
Tamshing Lhakhang	Choekhor	Bumthang	Lhakhang
Pedseling Lhakhang	Choekhor	Bumthang	Lhakhang
Dorjibee Lhakhang	Choekhor	Bumthang	Lhakhang
Dendupcholing Lhakhang	Choekhor	Bumthang	Lhakhang
Thangbi Lhuendrupchoedey Lhakhang	Choekhor	Bumthang	Gomdey
Taga Lhakhang	Choekhor	Bumthang	Lhakhang
Shudrag Lhakhang	Choekhor	Bumthang	Lhakhang
Thrasphel Lhakhang	Choekhor	Bumthang	Lhakhang
Saram Lhakhang	Choekhor	Bumthang	Lhakhang
Ugyen Shabchey Lhakhang	Choekhor	Bumthang	Lhakhang
Chokorling Dungkhor	Chokorling	Pema Gatshel	Dungkhor
Deezama Lhakhang	Chokorling	Pema Gatshel	Lhakhang
Gazawoong Lhakhang	Chokorling	Pema Gatshel	Lhakhang
Kerong Lopenchorten Lhakhang	Chokorling	Pema Gatshel	Lhakhang
Chongshing Kuenzang Choling Lhakhang	Chongshing	Pema Gatshel	Lhakhang
Youmzor Lhakhang	Chongshing	Pema Gatshel	Lhakhang
Mandi Lhakhang	Chongshing	Pema Gatshel	Lhakhang
Yuomzor dungkhor	Chongshing	Pema Gatshel	Dungkhor
Guyum Sangaycholing Lhakhang	Chongshing	Pema Gatshel	Lhakhang
Zambala Lhakhang	Chumey	Bumthang	Lhakhang
Namphur Lhakhang	Chumey	Bumthang	Lhakhang
Terzoe Lhakhang	Chumey	Bumthang	Lhakhang

Norbugang Lhakhang	Daga	Wangdue Phodrang	Lhakhang
Uma Chhoeling Goenpa	Daga	Wangdue Phodrang	Goenpa
Gyalpakha Lhakhang	Daga	Wangdue Phodrang	Lhakhang
Taksha Norbuding Lhakahang	Daga	Wangdue Phodrang	Lhakhang
Pasakha Aamai Neykhang	Darla	Chukha	Neykhang
Darla Tashi choeling Lhakhang	Darla	Chukha	Lhakhang
Ynagmalashing Dungkhor	Dechenling	Pema Gatshel	Dungkhor
Layshingri Dungkhor	Dechenling	Pema Gatshel	Dungkhor
Shingchongri Dungkhor	Dechenling	Pema Gatshel	Dungkhor
Kulamanti Dungkhor	Dechenling	Pema Gatshel	Dungkhor
Gonpawoong Dungkhor	Dechenling	Pema Gatshel	Dungkhor
Denchukkha Shivalaya Mandir	Denchukha	Samtse	Shivalaya Mandir
S/Jongkhar drashang	Deothang	Samdrup Jongkhar	Lhakhang
Samdrup Jongkhar dzongnang	Deothang	Samdrup Jongkhar	Lhakhang
Zangdopelri Lhakhang	Doethang	Samdrup Jongkhar	Lhakhang
Maecharkarmalingcholing Lhakhang	Doethang	Samdrup Jongkhar	Lhakhang
Dokar Tashichoding Lhakhang	Dogar	Paro	Lhakhang
Drakteng Lhakhang	Dogar	Paro	Lhakhang
Gemdralog Lhakhang	Dogar	Paro	Lhakhang
Kotey Phusisi Lhakhang	Dopshari	Paro	Lhakhang
Tading Lhakhang	Dopshari	Paro	Lhakhang
Thak Choe Lhakhang	Dopshari	Paro	Lhakhang
Sengdhyen Goendhey	Dorokha	Samtse	Gomdey
Dorkha School Chorten	Dorokha	Samtse	Chorten
Chumo Phu Lhakhang	Doteng	Paro	Lhakhang
Goensar Lhakhakhang	Doteng	Paro	Lhakhang
Khandro Chedu Goenpa	Doteng	Paro	Goenpa
Damthaykha Dechencholing	Doteng	Paro	Lhakhang
Doelpo Shedra Lhakhang	Doteng	Paro	Lhakhang
Ashi Lhakhang	Doteng	Paro	Lhakhang
Para Lhakhang	Doteng	Paro	Lhakhang
Tashidingkha L/khang	Drakteng	Trongsa	Lhakhang
Chakar zur L/khang	Drakteng	Trongsa	Lhakhang
Drakteng Dungkhor L/khang	Drakteng	Trongsa	Lhakhang
Refey Khamey Tshag-Jab dungkhor l/khang	Drakteng	Trongsa	Lhakhang
Kungarabten Drubday goenpa L/kahng	Drakteng	Trongsa	Lhakhang
Laptsa Goenpa Tashicholing	Drepong	Mongar	Lhakhang
Namgonepa yoocholing Lhaknag	Drepong	Mongar	Lhakhang
Namla memay Chorten Lhakhang	Drepong	Mongar	Lhakhang
Namdrup choling	Drujeygang	Dagana	Choling
Wongborang Lhakhang	Dungmin	Pema Gatshel	Lhakhang

Tomi Lhakhang	Dungmin	Pema Gatshel	Lhakhang
Dungmin Lhakhang	Dungmin	Pema Gatshel	Lhakhang
Wongborang Gonpa Lhakhang	Dungmin	Pema Gatshel	Lhakhang
Aomla Lhakhang	Dungmin	Pema Gatshel	Lhakhang
Lhakhang	Dungtoe	Samtse	Lhakhang
Tshogdag Langpoi Nye Lhakhang	Dzomi	Punakha	Lhakhang
Jimthang Lhakhang	Dzomi	Punakha	Lhakhang
Jojogoenpa Lhakhang	Dzomi	Punakha	Lhakhang
Wangchu lo Dzong	Eusu	Ha	Dzong
Chorkoling Tshulakhang	Eusu	Ha	Lhakhang
Tagchug lungtsho lakhang	Eusu	Ha	Lhakhang
Sharkada Lakhang	Eusu	Ha	Lhakhang
Gangtey Goenpa	Gangtey	Wangdue Phodrang	Lhakhang
Chuchig Zhay Lhakhang	Gangtey	Wangdue Phodrang	Lhakhang
Gyela Goenkhang	Gangtey	Wangdue Phodrang	Lhakhang
Kuenzang Chhoeling Lhakhang	Gangtey	Wangdue Phodrang	Lhakhang
Gesar Lhakhang	Gangzur	Lhuentse	Lhakhang
Jangchubling dratshang	Gangzur	Lhuentse	Dratshang
Tongling Lhakhang	Gangzur	Lhuentse	Lhakhang
Ngar Lhakhang	Gangzur	Lhuentse	Lhakhang
Yodra Gondey Lhakhang	Gangzur	Lhuentse	Lhakhang
Matshig Pokto Lhakhang	Gasetsho Gom	Wangdue Phodrang	Lhakhang
Shingkhey Lhakhang	Gasetsho Wom	Wangdue Phodrang	Lhakhang
Thegchhen Ugyen Drak Lhakhang	Gasetsho Wom	Wangdue Phodrang	Lhakhang
Geekha Lhakhang	Gasetsho Wom	Wangdue Phodrang	Lhakhang
Gangrim Lakhang	Gaykedling	Ha	Lhakhang
Phuntsho Darjaycholing Lakhang	Gaykedling	Ha	Lhakhang
Geling Sa-ngag choeling Lhakhang	Geling	Chukha	Lhakhang
Kuenga choeling Gonpa	Geling	Chukha	Lhakhang
Gesarling Lhakhang	Gesarling	Dagana	Lhakhang
Tashigang Lhakhang	Getana	Chukha	Lhakhang
Tshebji Lhakhang	Getana	Chukha	Lhakhang
Phutsa Lhakhang	Getana	Chukha	Lhakhang
Chidungkhar Lhakhang	Gomdhar	Samdrup Jongkhar	Lhakhang
Aumshing Lhakhang	Gomdhar	Samdrup Jongkhar	Lhakhang
Phendhecholing Lhakhang	Gomdhar	Samdrup Jongkhar	Lhakhang
Drongshing Lhakhang	Gomdhar	Samdrup Jongkhar	Lhakhang
Mandir (Narphung)	Gomdhar	Samdrup Jongkhar	Lhakhang
Pangthang Lhakhang	Gongdue	Mongar	Lhakhang
Phoksa Lhakhang	Gongdue	Mongar	Lhakhang
Damkhar Lhakhang	Gongdue	Mongar	Lhakhang
Balajangchunbcholing Lhakhang	Gongdue	Mongar	Lhakhang

Goshing Trong Lhakhang	Goshing	Zhemgang	Lhakhang
Lichibi Lhakhang	Goshing	Zhemgang	Lhakhang
Mewangang Lhakhang	Goshing	Zhemgang	Lhakhang
Samcholing Gomdey	Goshing	Zhemgang	Gomdey
Choekhorling Goenpa	Guma	Punakha	Lhakhang
Zurig Gongma Lhakhang	Hungrel	Paro	ZGL
La Teng Lhakhang	Hungrel	Paro	Lhakhang
Chudra Lhakhang	Hungrel	Paro	Lhakhang
Labar Lhakhang	Jamkhar	Trashiyangtse	Lhakhang
Yesehry choling Goenpa	Jamkhar	Trashiyangtse	Goenpa
Yumchey Lhakhang	Jarey	Lhuentse	Lhakhang
Goenpagang Lhakhang	Jarey	Lhuentse	Lhakhang
Kiranang dungkhor	Jarey	Lhuentse	dungkhor
Yabi Lhakhang	Jarey	Lhuentse	Lhakhang
Jigmecholing Dratshang	Jigmecholing	Sarpang	Dratshang
Chungshing Lhakhang	Jigmecholing	Sarpang	Lhakhang
Singsiri Chimi drakpa Lhakhang	Jurmey	Mongar	Gomdey
Rakta Sonam RinchemLhakhang	Jurmey	Mongar	Lhakhang
Dungkhor cholingLhakhang	Jurmey	Mongar	Dratshang
Roro nam ugyen gytsheLhakhang	Jurmey	Mongar	Dratshang
Ringphu lungten Gerwang Lhakhang	Jurmey	Mongar	Lhakhang
Bayoul choda Gyerwang Lhakhang	Jurmey	Mongar	Lhakhang
Nganphu Yeshay Choiling Lhakhang	Jurmey	Mongar	Lhakhang
Chorten	Kana	Dagana	Chorten
Chorten	Kana	Dagana	Chorten
Chorten	Kana	Dagana	Chorten
Tapgang Lhakhang	Kana	Dagana	Lhakhang
Rongthung Naktshang Lhakhang	Kanglung	Trashigang	Lhakhang
Thukten Chekorling Shedra (Zangdopelri)	Kanglung	Trashigang	Shedra
Sanga Dorji Lhakhang	Kanglung	Trashigang	Gomdey
Resharlog Namgay Lhakhang	Kangpara	Trashigang	Gomdey
Phuntsho Tshering Dungkhor	Kangpara	Trashigang	Dungkhor
Merdha Mongdrang Lhakhang	Kangpara	Trashigang	Gomdey
Lhendup Samtencholing Lhakhang	Kangpara	Trashigang	Shedra
Kuenphen Choling Lhakhang	Kangpara	Trashigang	Gomdey
Jarokharshong Chorten	Kangpara	Trashigang	Chorten
Jungne drak Lakang	Katsho	Ha	Lhakhang
Katsho Goempa	Katsho	Ha	Goenpa
Drolung Gonpa	Kawang	Thimphu	Drubdey
Tango Shedra	Kawang	Thimphu	Shedra
Chari Drubdey	Kawang	Thimphu	Drubdey

Ugyen Dongacholing	Kawang	Thimphu	Lhakhang
Paygiri drubdey	Kawang	Thimphu	Drubdey
Dodedra shedra	Kawang	Thimphu	Shedra
Decheling Gonpa	Kawang	Thimphu	Drubdey
Pumla Lhakhang	Kawang	Thimphu	Lhakhang
Thujidra Lhakhang	Kawang	Thimphu	Lhakhang
Wangditse Lhakhang	Kawang	Thimphu	Lhakhang
Bay Langdrag Nye Lhakhang	Kazhi	Wangdue Phodrang	Lhakhang
Chagina Lhakhang	Kazhi	Wangdue Phodrang	Lhakhang
Leymi Tshering Gyeltshen Lhakhang	Khaling	Trashigang	Gomdey
Leymi Gomchen Dorji Lhakhang	Khaling	Trashigang	Dungkhori
Jadrunge Lhakhang	Khaling	Trashigang	Gomdey
Leymi Tashi Choling Lhakhang	Khaling	Trashigang	Gomdey
Khawar Lhakhang	Khar	Pema Gatshel	Lhakhang
Khengzor Lhakhang	Khar	Pema Gatshel	Lhakhang
Thongphu Gonpa	Khar	Pema Gatshel	Lhakhang
Gyelmarkhar Thingrab tenling Lhakhang	Khengkhar	Mongar	Lhakhang
Memkhar Lhakhang	Khoma	Lhuentse	Lhakhang
Zepadhur Lhakhang	Khoma	Lhuentse	Lhakhang
Sangay Iodu Lhakhang	Khoma	Lhuentse	Lhakhang
Berpa Lhakhang	Khoma	Lhuentse	Lhakhang
Karphu Lhakhang	Khoma	Lhuentse	Lhakhang
Samdrubcholing Lhakhang	Khoma	Lhuentse	Lhakhang
Nyalamdung Naktshang	Khoma	Lhuentse	Naktsang
Damphu Town Lhakhang	Kikhorthang	Tsirang	Lhakhang
Nimshong L/khang	Korphu	Trongsa	Lhakhang
Korphu L/khang	Korphu	Trongsa	Lhakhang
Korphu Dungkhor	Korphu	Trongsa	Lhakhang
Nabji Dungkhor	Korphu	Trongsa	Dungkhori
Korphu Gomday	Korphu	Trongsa	Gomdey
Ugyenphu Lhakhang	Kurtoe	Lhuentse	Lhakhang
Khambu Lhakhang	Kurtoe	Lhuentse	Lhakhang
Tsendenpokpa Lhakhang	Kurtoe	Lhuentse	Lhakhang
Rin Pung Lhakhang	Lamgong	Paro	Lhakhang
Tseto Goenpa Lhakhang	Lamgong	Paro	Lhakhang
Bayling Lhakhang	Langthil	Trongsa	Lhakhang
Baling Lhakhang	Langthil	Trongsa	Lhakhang
Wangkhar L/khang	langthil	Trongsa	Lhakhang
Sheling L/khang	langthil	Trongsa	Lhakhang
Jangbi L/khang	langthil	Trongsa	Lhakhang
Koshala Drolong Dungkhor L/khang	Langthil	Trongsa	Lhakhang
Taktshi L/khang	Langthil	Trongsa	Lhakhang

Lingtey L/khang	Langthil	Trongsa	Lhakhang
Baling Tobgay dunghor l/khang	Langthil	Trongsa	Lhakhang
Thrsebee Tashichholing	Langthil	Trongsa	Gomdey
Tsephu goenpa Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Batselingdrupdra Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Tashicholing Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Ngoengacholing Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Dungmanma (T-49) Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Woongthigdunghor Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Sangacholing Lhakhang	Lauri	Samdrup Jongkhar	Lhakhang
Dompala Lhakhang	Limbu	Punakha	Lhakhang
Jarokharshong Chorten	Lumang	Trashigang	Chorten
Dunggan Lhakhang	Lungo	Gasa	Lhakhang
Gadrak Changchu Lhakhang	Lungyni	Paro	Lhakhang
Dingshingzor Lhakhang	Martsala	Samdrup Jongkhar	Lhakhang
Thongpashingzor Lhakhang	Martsala	Samdrup Jongkhar	Lhakhang
Kakani Lhakhang	Martsala	Samdrup Jongkhar	Lhakhang
Tsholingkhar Lhakhang	Martsala	Samdrup Jongkhar	Lhakhang
Barkha Lhakhang	Menbi	Lhuentse	Lhakhang
Menjabi Lhakhang	Menbi	Lhuentse	Lhakhang
Dangling Lhakhang	Menbi	Lhuentse	Lhakhang
Takila Lhakhang	Menbi	Lhuentse	Lhakhang
Mendrelgang Lhakhang	Mendrelgang	Tsirang	Lhakhang
Mendrelgang Hindu Lhakhang	Mendrelgang	Tsirang	Lhakhang
Khashiteng Lhakhang	Merak	Trashigang	Gomdey
Tongthrong Lhakhang	Metsho	Lhuentse	Lhakhang
Duwazhing Lhakhang	Metsho	Lhuentse	Lhakhang
Zhongmay Lhakhang	Metsho	Lhuentse	Lhakhang
Tshaluney lhakhaqng	Mewang	Thimphu	Lhakhang
Semo Lhakhang	Mewang	Thimphu	Lhakhang
Datong Lhakhang	Mewang	Thimphu	Lhakhang
Dramisa Lhakhang	Mewang	Thimphu	Lhakhang
Khasakha Lhakhang	Mewang	Thimphu	Lhakhang
wangzhing naktsang Lhakhang	Minjey	Lhuentse	Naktsang
Sengling Lhakhang	Minjey	Lhuentse	Lhakhang
Phunchola Lhakhang	Mongar	Mongar	Dratshang
Nangling Lhakhang (Pema Dorji)	Mongar	Mongar	Lhakhang
Yakgang Sanga Choling Lhakhang	Mongar	Mongar	Lhakhang
Wengkhar Ngatshang Lhakhang	Mongar	Mongar	Dratshang
Wengkhar Kadam Lhakhang	Mongar	Mongar	Lhakhang
Khujula Chhoeling Phodrang Lhakhang	Nahi	Wangdue Phodrang	Lhakhang
Tandin Lhakhang	Nahi	Wangdue Phodrang	Lhakhang

Tshendu Goenpa	Naja	Paro	Goenpa
Tshedra Goenpa	Naja	Paro	Goenpa
Jawargoenpa jangchub Choling	Naja	Paro	Choling
Nagu Goenpai Lhakhang	Naja	Paro	Lhakhang
Tali Thegling dratshang	Nangkor	Zhemgang	Dratshang
Buli Goenpa Lhakhang	Nangkor	Zhemgang	Lhakhang
Tali Lhakhang	Nangkor	Zhemgang	Lhakhang
Duenmang Lhakhang	Nangkor	Zhemgang	Lhakhang
Zhobling Lhakhang	Nangkor	Zhemgang	Lhakhang
Kikhar Lhakhang	Nangkor	Zhemgang	Lhakhang
Goling Lhakhang	Nangkor	Zhemgang	Lhakhang
Phuntsh Peling Lhakhang	Nangkor	Zhemgang	Lhakhang
Tshaidang Lhakhang	Nangkor	Zhemgang	Lhakhang
Tshaidang Gomdey	Nangkor	Zhemgang	Gomdey
Dakphai Lhakhang	Nangkor	Zhemgang	Lhakhang
Dakphai Gortab Lhakhang	Nangkor	Zhemgang	Lhakhang
Kamjong Lhakhang	Nangkor	Zhemgang	Lhakhang
Rashigonpa Lhakhang	Nanong	Pema Gatshel	Lhakhang
Tokari Gari Lhakhang	Nanong	Pema Gatshel	Lhakhang
Wongchiloo Lhakhang	Nanong	Pema Gatshel	Lhakhang
Wilegtang Lhakhang	Nanong	Pema Gatshel	Lhakhang
Tokari (Tshering) Lhakhang	Nanong	Pema Gatshel	Lhakhang
Thngthung gonpa Lhakhang	Nanong	Pema Gatshel	Lhakhang
Ngangla Trong Lhakhang	Ngangla	Zhemgang	Lhakhang
Rebati Lhakhang	Ngangla	Zhemgang	Lhakhang
Panbang Lhakhang	Ngangla	Zhemgang	Lhakhang
Yadi sanga choling Lhakhang	Ngatshang	Mongar	Lhakhang
Kungacholing :Lhakhang	Ngatshang	Mongar	Lhakhang
Sherubcholing Lhakhang	Pema	Mongar	Lhakhang
wangchuk	Ngatshang	Mongar	Lhakhang
Gashari Lhakhang	Norbugang	Pema Gatshel	Lhakhang
Tshishingzor Lhakhang	Norbugang	Pema Gatshel	Lhakhang
Tshishingzor Dungkhon	Norbugang	Pema Gatshel	Dungkhon
Norbugang Dungkhon	Norbugang	Pema Gatshel	Dungkhon
Samtengang Lhakhang	Nyisho	Wangdue Phodrang	Lhakhang
Nyishokha Lhakhang	Nyisho	Wangdue Phodrang	Lhakhang
Gashing gaon Chorten	Pagli	Samtse	Chorten
Shiva Mandir (Pvt)	Pagli	Samtse	Shivalaya
Durga Mandir	Pagli	Samtse	Mandir
Mamung Trong Lhakhang	Phangkhar	Zhemgang	Durga Mandir
Tashibi Yukhar Lhakhang	Phangkhar	Zhemgang	Lhakhang
Pantang Lhakhang	Phangkhar	Zhemgang	Lhakhang

Pongchula Lhakhang	Phangkhar	Zhemgang	Lhakhang
Gujong Dungkhor Lhakhang	Phangkhar	Zhemgang	Lhakhang
Tayel Goenpai Dargye Goenpa	Phangyul	Wangdue Phodrang	Goenpa
Omshadrem Lhakhang	Phongmey	Trashigang	Shedra
Phongmey Hongmen Choling Lhakhang	Phongmey	Trashigang	Gomdey
Shokhang Zhabdrung Lhakhang	Phongmey	Trashigang	Gomdey
Thongrong Samten Choling Lhakhang	Phongmey	Trashigang	Gomdey
Jangnyenma Lhakhang	Phongmey	Trashigang	Gomdey
Pengtse Samdrup Choling Lhakhang	Phongmey	Trashigang	Gomdey
Dodril Dongaling Shedra	Phongmey	Trashigang	Shedra
Rinchending Lhakhang	Phuntsholing	Chukha	Dratshang
Pachu Dangra	Phuntsholing	Chukha	Goenpa
Nga-sumi Ney Lhakhang	Phuntsholing	Chukha	Lhakhang
Namgay Choeling Lhakhang	Phuntsholing	Chukha	Lhakhang
Thangchu goenpa Lhakhang	Phuntshothang	Samdrup Jongkhar	Lhakhang
Thekcho Kuenga Choling Lhakhang	Radhi	Trashigang	Nunnery
Namdrol Choling Lhakhang	Radhi	Trashigang	Gomdey
Jangchub Chorten	Radhi	Trashigang	Chorten
Zamding Lhakhang	Rubesa	Wangdue Phodrang	Lhakhang
Ulla Lhakhang	Rubesa	Wangdue Phodrang	Lhakhang
Tsholing goma Lhakhang	Saleng	Mongar	Lhakhang
Thridangbi Lhankhang	Saleng	Mongar	Lhakhang
Mangling tokapang Lhakhang	Saleng	Mongar	Lhakhang
Kalapang Gadencholing Lhakhang	Saleng	Mongar	Lhakhang
Broksa Ugyencholing Lhakhang	Saleng	Mongar	Lhakhang
Wama Lhakhang	Salimbi	Mongar	Lhakhang
Dakcha laye Lhakhang	Salimbi	Mongar	Lhakhang
Zegoen Lhakhang	Salimbi	Mongar	Lhakhang
Zegoen jangchub dorji dungkhor Lhakhang	Salimbi	Mongar	Lhakhang
Pudup tshuk Lhakhang	Samar	Ha	Lhakhang
Balam wang ge Lhakhang	Samar	Ha	Lhakhang
Khapti Kegphu Gonpa Lhakhang	Samkhar	Trashigang	Gomdey
Taling Gonpa Lhakhang	Samkhar	Trashigang	Gomdey
Khapti Kadam Lhakhang	Samkhar	Trashigang	Gomdey
Pam Drodul Pema Yeling Lhakhang	Samkhar	Trashigang	Gomdey
Zhu shing Dingkha Gonpa	Sampheling	Chukha	Lhakhang
Pagsam Singye	Sampheling	Chukha	Zangdopelri
Guest House Chorten	Samtse	Samtse	Chorten
NIE Chorten	Samtse	Samtse	Chorten
Tercholing Lhakhang (Lamitar)	Samtse	Samtse	Lhakhang
Guru Lhakhang (Bukay)	Samtse	Samtse	Lhakhang

Tasim Shiva Mandir	Samtse	Samtse	Shivalaya Mandir
Rabgatse Lhakhang	Sephu	Wangdue Phodrang	Lhakhang
Samdrupcholing Lhakhang	Sershong	Sarpang	Lhakhang
Woedselgang Goenpa	Sershong	Sarpang	Goenpa
Deptshang ugyencholing Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Larjab Pema Gatshel Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Drenphu ugyencholing Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Khandrophung Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Moenmula Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Sangacholing Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Tashithangjay Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Juenmay tashicholing Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Moenmula karchung dongkhor Lhakhang	Serthi	Samdrup Jongkhar	Lhakhang
Samdro Cholling Lhakhang	Shaba	Paro	Lhakhang
Neyphug Tshugla Khang	Shaba	Paro	NL
Bemori Lhakhang	Shaba	Paro	Lhakhang
Boetam Lhakhang	Shaba	Paro	Lhakhang
Nyephu Goem Gonpa	Shaba	Paro	Goenpa
Serchong Choling Lhakhang	Shermung	Mongar	Gomdey
Sherchong Tsechuphu Phuntsho Lhakhang	Shermung	Mongar	Lhakhang
Sherchong Pangtala Lhakhang Dendup	Shermung	Mongar	Lhakhang
Sherchong Lhakhang Ngawang	Shermung	Mongar	Lhakhang
Sonekhar Riling Lhakhang	Shermung	Mongar	Gomdey
Sonekhar Bomay Lhakhang Kelzang Wangdi	Shermung	Mongar	Lhakhang
Sonekhar Lhakhang Kinga Raday Lhakhang	Shermung	Mongar	Lhakhang
Thiling Lhagong goenpa lop sangay Dorji	Shermung	Mongar	Lhakhang
Thiling Barka Lhakhang Karma	Shermung	Mongar	Lhakhang
Jabgang pempa Lhakhang	Shermung	Mongar	Lhakhang
Jabgang Chorten Lhakhang	Shermung	Mongar	Lhakhang
Jabgang Tashi Lhakhang	Shermung	Mongar	Lhakhang
Jabgang Bopay Lhakhang	Shermung	Mongar	Lhakhang
Gangmung Lhakhang	Shermung	Mongar	Lhakhang
Shingkar Wambu Lhakhang	Shingkar	Zhemgang	Lhakhang
Radhi Tashiding Lhakhang	Shingkar	Zhemgang	Lhakhang
Zangling Lhakhang	Shingkar	Zhemgang	Lhakhang
Thajong Lhakhang	Shingkar	Zhemgang	Lhakhang
Jatshabi Lhakhang	Shingkar	Zhemgang	Lhakhang
Peseng Zowachador Lhakhang	Shingkar	Zhemgang	Lhakhang

Raha Lhakhang	Shongphu	Trashigang	Gomdey
Kuenphen Chekhorling Lhakhang	Shongphu	Trashigang	Gomdey
Dungphu Gonpa Lhakhang	Shongphu	Trashigang	Gomdey
Neykhang Lhakhang	Shongphu	Trashigang	Gomdey
Galing Tshering Dungkhor Lhakhang	Shongphu	Trashigang	Dungkhor
Neykhang Dekiling Lhakhang	Shongphu	Trashigang	Gomdey
Galing Drongmay Lhakhang	Shongphu	Trashigang	Gomdey
Kidpu Choling Lhakhang	Shongphu	Trashigang	Gomdey
Sangcham Gonpa Lhakhang	Shongphu	Trashigang	Gomdey
Chemari Lhakhang	Shongphu	Trashigang	Gomdey
Dramang Ridiser Lhakhang	Shongphu	Trashigang	Gomdey
Changmey Lhakhang	Shongphu	Trashigang	Gomdey
Dangling Dungkhor Lhakhang	Shongphu	Trashigang	Dungkhor
Bartsheri Lhakhang	Shumar	Pema Gatshel	Lhakhang
Gyelpodrangsa Lhakhang	Shumar	Pema Gatshel	Lhakhang
Dengtsirawa Lhakhang	Shumar	Pema Gatshel	Lhakhang
Toepalung Lhakhang	Shumar	Pema Gatshel	Lhakhang
Serkhegpa Sanag Dorji Lhakhang	Shumar	Pema Gatshel	Lhakhang
Ana Goempa	Sombaykha	Ha	Goenpa
Pelri Dorji Dhen Tshuglakhang	Talo	Punakha	Tshuglakhang
Nobgang Yulkhangna Lhakhang	Talo	Punakha	Lhakhang
Dashigang Gyelwa Lhakhang	Talo	Punakha	Lhakhang
Nalenda Sona Gatshel Lhakhang	Talo	Punakha	Lhakhang
Namkha Lhakhang	Tang	Bumthang	Lhakhang
Anu Lhakhang	Tang	Bumthang	Lhakhang
Ugyencholing Dzong	Tang	Bumthang	Lhakhang
Bumphog Lhakhang	Tang	Bumthang	Lhakhang
Rimochen	Tang	Bumthang	Lhakhang
Dorjitse Lhakhang	Tang	Bumthang	Gomdey
Dechenpelrithang Lhakhang (HM's)	Tang	Bumthang	Lhakhang
Kela L/khang	Tangsibji	Trongsa	Lhakhang
Ugyen Thongdra L/khang	Tangsibji	Trongsa	Lhakhang
Chendbji Chorten	Tangsibji	Trongsa	Chorten
Tendu Dratsang	Tendu	Samtse	Dratshang
Tendu School Chorten	Tendu	Samtse	Chorten
Chorten (Ap Daw Tshering)	Tendu	Samtse	Chorten
D-Bindu New Lhakhang	Tendu	Samtse	Lhakhang
Zimbula Peling Goenpa	Teotsho	Trashiyangtse	Lhakhang
Dumang Lhakhang	Teotsho	Trashiyangtse	Lhakhang
ThongThong Gonpa	Thangrong	Mongar	Lhakhang
Changshing Gonpa Lop Gyeltshen	Thangrong	Mongar	Lhakhang
Ri phu Lhakhang (Sangay Drakpa)	Thangrong	Mongar	Lhakhang

Tongphuyoung Lhakhang (Karma Dorji)	Thangrong	Mongar	Lhakhang
Trebang Nimadorji Dungkhor Lhakhang	Thangrong	Mongar	Lhakhang
Changzhong Lhakhang	Thangrong	Mongar	Lhakhang
Bajo Thangu Lhakhang	Thedtsho	Wangdue Phodrang	Lhakhang
Gashari Lhakhang	Thrimshing	Trashigang	Gomdey
Bongzor Lhakhang	Thrimshing	Trashigang	Gomdey
Yongderi Lhakhang	Thrimshing	Trashigang	Gomdey
Thungkhar Serkem Lhakhang	Thrimshing	Trashigang	Gomdey
Tshogphel Lhakhang	Thrimshing	Trashigang	Gomdey
Thekshok Pema Yuling	Thrimshing	Trashigang	Gomdey
Mani Dangray	Thrimshing	Trashigang	Mani Dangray
Gomphu Kora Dratshang	Tongzhangtshen	Trashiyangtse	Dratshang
Bainangkhar Ugyen choling Lhakhang	Tongzhangtshen	Trashiyangtse	Lhakhang
Druk Drasamdrup choling Lhakhang	Tongzhangtshen	Trashiyangtse	Lhakhang
Zatshen Choling Lhakhang	Tongzhangtshen	Trashiyangtse	Lhakhang
Dungkhor Lhakhang	Trashiyangtse	Trashiyangtse	Lhakhang
Teng Gomdhey Lhakhang	Trashiyangtse	Trashiyangtse	Lhakhang
Thamchu Khenpo Dratshang	Trashiyangtse	Trashiyangtse	Lhakhang
Tama Goenpa Gomdey	Trong	Zhemgang	Gomdey
Tama Lhakhang	Trong	Zhemgang	Lhakhang
Gomphu Lhakhang	Trong	Zhemgang	Lhakhang
Berti Trong Lhakhang	Trong	Zhemgang	Lhakhang
Trong Lhakhang	Trong	Zhemgang	Lhakhang
Dangkhar Lhakhang	Trong	Zhemgang	Lhakhang
Zurphey Lhakhang	Trong	Zhemgang	Lhakhang
Subrang Lhakhang	Trong	Zhemgang	Lhakhang
Gunda Dranamling Dungkhor Lhakhang	Tsakling	Mongar	Lhakhang
Gunda Penden Choling Dungkhor Lhakhang	Tsakling	Mongar	Lhakhang
Changlagang baryousen sum Lhakhang	Tsakling	Mongar	Lhakhang
Thumling Tashicholing Dungkhor Lhakhang	Tsakling	Mongar	Lhakhang
Nartshe Dungkhor Choling Lhakhang	Tsakling	Mongar	Lhakhang
Phangray Lhakhang	Tsenkhar	Lhuentse	Lhakhang
Takchu Lhakhang	Tsenkhar	Lhuentse	Lhakhang
Tongphugang Lhakhang	Tsenkhar	Lhuentse	Lhakhang
Namdrupling Gonpa dratshang	Tsenkhar	Lhuentse	Dratshang
Lhading Goenpa	Tsento	Paro	Goenpa
Ugyen Tshemo Tsugla Khang	Tsento	Paro	UTL
Droley Phu Lhakhang	Tsento	Paro	Lhakhang
Daga Tashi Yangtse Dzong	Tseza	Dagana	Dzong
Shakthong goenpa	Tseza	Dagana	Goenpa
Samey Lhakhang	Tseza	Dagana	Lhakhang

Sarbum Lhakhang	Tshamang	Mongar	Lhakhang
Banjar Lhakhang	Tshamang	Mongar	Lhakhang
Dramaling Nangar Lhakhang	Tshamang	Mongar	Lhakhang
Ganglapong Lhakhang	Tshamang	Mongar	Lhakhang
Dauthrey Lhakhang	Tsirangtoe	Tsirang	Lhakhang
Boteykharka Shivalaya Mandir	Ugentse	Samtse	Shivalaya Mandir
Raigaon Shivalaya Mandir	Ugentse	Samtse	Shivalaya Mandir
Ugentse Namgay Khanzang Chorten	Ugentse	Samtse	Chorten
Umling Lhakhang	Umling	Sarpang	Lhakhang
Throlnang Lhakhang	Uzorong	Trashigang	Gomdey
Riegoem Lhakhang	Uzorong	Trashigang	Gomdey
Neydhen Gatshel Lhakhang	Uzorong	Trashigang	Gomdey
Dhensalo Lhakhang	Uzorong	Trashigang	Gomdey
Kir Khu Gonpa	Wangchang	Paro	Goenpa
Gomdra Lo Lhakhang	Wangchang	Paro	Lhakhang
Yarphu Tsachilu Lhakhang	Wangphu	Samdrup Jongkhar	Lhakhang
Trashithang Jaling Lhakhang	Yallang	Trashiyangtse	Lhakhang
Yalang Gaykar Goenpa	Yallang	Trashiyangtse	Lhakhang
Chema Lhakhang	Yallang	Trashiyangtse	Lhakhang
Phungyang Tshokhang	Yallang	Trashiyangtse	Tshokhang
Durung Ugyen Wangchuk Lhakhang	Yangneer	Trashigang	Gomdey
Gomchen Langala Lhakhang	Yangneer	Trashigang	Gomdey
Talung Dopo Lhakhang	Yangneer	Trashigang	Gomdey
Lama Rinchen Lhakhang	Yangneer	Trashigang	Gomdey
Tshenmey Chokhorling Lhakhang	Yangneer	Trashigang	Gomdey
Shingkhar Gonpa Lhakhang	Yangneer	Trashigang	Gomdey
Durung Lhakhang	Yangneer	Trashigang	Gomdey
Chazam Duptho Thongthong Gyelpo Lhakhang	Yangneer	Trashigang	Lhakhang
Tokden Choling Dubdey	Yangneer	Trashigang	Choling
Thungo Lhakhang	Yurung	Pema Gatshel	Lhakhang
Tashicholing Lhakhang	Yurung	Pema Gatshel	Lhakhang
Dungsingma Lhakhang	Yurung	Pema Gatshel	Lhakhang
Chengri dungkhor Lhakhang	Yurung	Pema Gatshel	Lhakhang
Phunsumburi Lhakhang (Peljor wangdi)	Yurung	Pema Gatshel	Lhakhang
Phunsumburi Lhakhang (Jangchu dendup)	Yurung	Pema Gatshel	Lhakhang
Gomtshang Lhakhang	Yurung	Pema Gatshel	Lhakhang
Yanglikhoi Lhakhang	Yurung	Pema Gatshel	Lhakhang
Gypkha Lhakhang	Yurung	Pema Gatshel	Lhakhang
Zobel Lhakhang	Zobel	Pema Gatshel	Lhakhang

Resinang Lhakhang	Zobel	Pema Gatshel	Lhakhang
Showmarthung Lhakhang	Zobel	Pema Gatshel	Lhakhang
Layshingkar Lhakhang	Zobel	Pema Gatshel	Lhakhang
Chungkhag gonpa Lhakhang	Zobel	Pema Gatshel	Lhakhang
Bachok Lhakhang	Zobel	Pema Gatshel	Lhakhang
Leteri Lhakhang	Zobel	Pema Gatshel	Lhakhang
Gonpasingma Lhakhang	Zobel	Pema Gatshel	Lhakhang

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