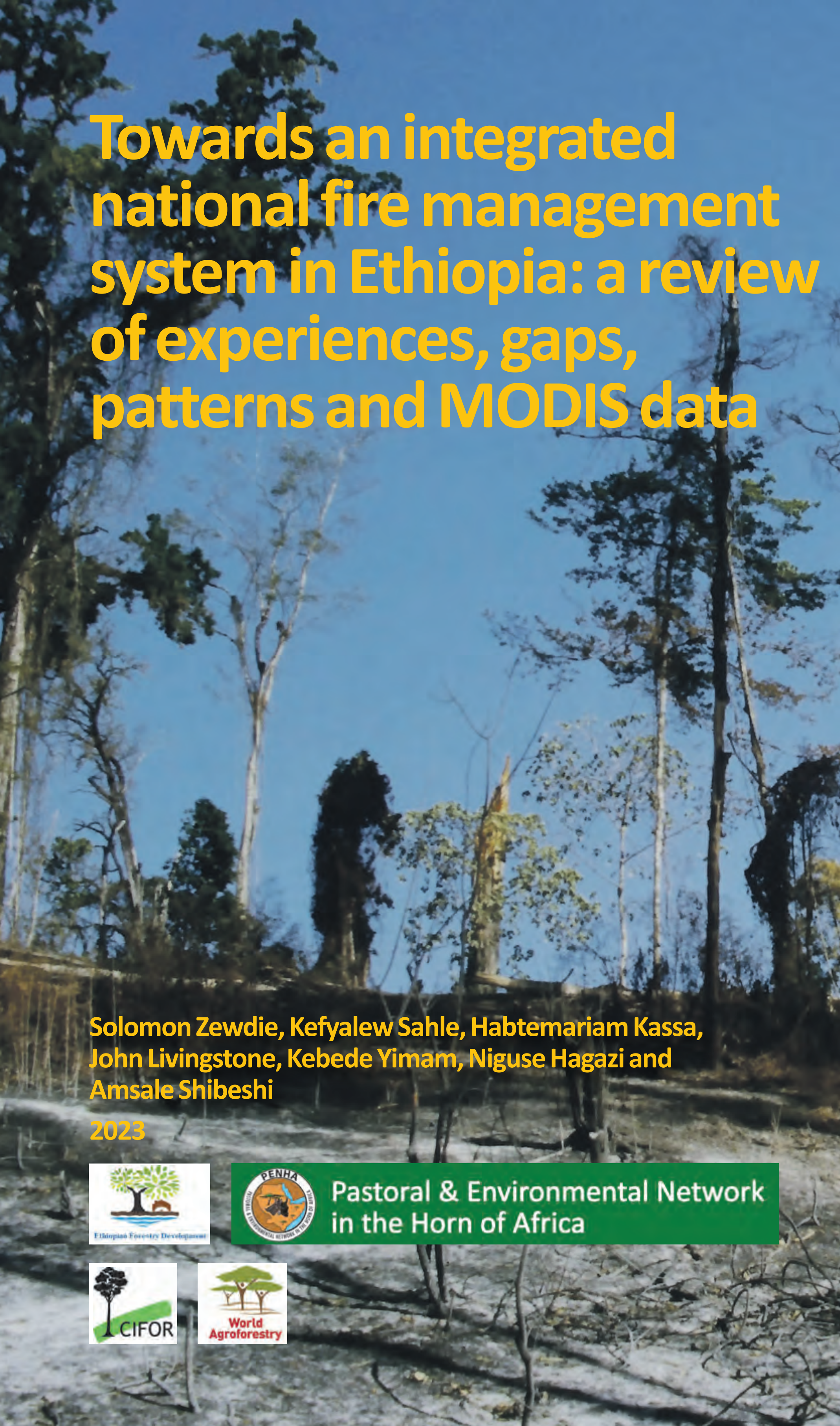


Towards an integrated national fire management system in Ethiopia: a review of experiences, gaps, patterns and MODIS data

Solomon Zewdie, Kefyalew Sahle, Habtemariam Kassa, John Livingstone, Kebede Yimam, Niguse Hagazi and Amsale Shibeshi

2023

Ethiopian Forestry Development

PENHA
Pastoral & Environmental Network in the Horn of Africa

CIFOR

World Agroforestry

The Pastoral and Environmental Network in the Horn of Africa (PENHA), founded in 1989, is a regional NGO, registered in the UK and headquartered in London. PENHA operates across the IGAD region, with country offices in Ethiopia and Somaliland. PENHA combines project implementation, research, and policy analysis. PENHA focuses on pastoralism, rangelands, and dry forests, and addresses broader development issues, with an emphasis on participation and inclusion.

Tropenbos International (TBI) envisions a future in which forests and trees are used sustainably for the benefit of local people and the global community. By using evidence to make conscious choices and finding the right balance between the needs of all stakeholders involved, TBI contributes to sustainable solutions for forested landscapes. TBI works to improve the livelihoods of local commu¬nities, as well as bring significant benefits to global society through climate change mitigation and biodiversity conservation. TBI was established in 1986 and is registered in the Netherlands. Since 2017, it became a network of independent member organizations, and with other partners, works in more than ten tropical countries worldwide.

This review was prepared under the Working Landscape programme of Tropenbos International, financed by the Ministry of Foreign Affairs of the Netherlands. The opinions and views expressed in this report are the sole responsibility of the authors and do not necessarily reflect the opinions and views of Tropenbos International or the Ministry of Foreign Affairs of the Netherlands.

Copyright: © 2023. The Pastoral and Environmental Network in the Horn of Africa and Tropenbos International.

Text may be reproduced for non-commercial purposes, citing the source.

Citation: Zewdie S, Sahle K, Kassa H, Livingstone J, Yimam K, Hagazi N and Shibeshi A. 2023. Towards an integrated wildfire management system in Ethiopia. Review of experiences and gaps, and MODIS data-based identification of patterns and hotspot areas. PENHA, Addis Ababa, Ethiopia and Tropenbos International, Ede, the Netherlands.

ISBN: 978-1-911614-15-9 (paper copy) **ISBN:** 978-1-911614-16-6 (Digital)

Cover pictures (front and back)**:** Burned area in the Bale Mountains. Being able to collect data on areas burned is an essential component of fire management. Photos: GFMC.

Editing: Nick Pasiecznik (Tropenbos International)

Layout: Andy Smith + Denise Bell (info@smithplusbell.com)

PENHA Ethiopia
PO Box 26975/1000
Addis Ababa
Ethiopia
info@penhaethiopia.org
www.penhanetwork.org

Ethiopian Forestry Development (EFD)
Arat Kilo
PO Box 24536/1000, Addis Ababa, Ethiopia
+251 11 6460980
info@efd.gov.et
www.efd.gov.et

Tropenbos International
Horaplantsoen 12
6717LT Ede
the Netherlands
tropenbos@tropenbos.org
www.tropenbos.org

Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF)
CIFOR-ICRAF Ethiopia Office, c/o ILRI, Gurd Shola PO Box 5689, Addis Ababa, Ethiopia
+251 11 617 2000
www.cifor-icraf.org

Towards an integrated national fire management system in Ethiopia: a review of experiences, gaps, patterns and MODIS data

Solomon Zewdie, Kefyalew Sahle, Habtemariam Kassa, John Livingstone, Kebede Yimam, Niguse Hagazi and Amsale Shibeshi

Solomon Zewdie Forestry and climate change consultant, Addis Ababa, Ethiopia (zew172@yahoo.com)
Kefyalew Sahle Lecturer, GIS and Remote Sensing, Wondo Genet College of Forestry and Natural Resources, Hawassa University, Hawassa, Ethiopia (kefyalewsahle.k@gmail.com)
Habtemariam Kassa Principal scientist, CIFOR-ICRAF, Addis Ababa, Ethiopia (h.kassa@cifor-icraf.org)
John Livingstone Regional policy officer, PENHA, Addis Ababa, Ethiopia (jklivingstone@hotmail.com)
Kebede Yimam Director general, Ethiopia Forestry Development (EFD), Addis Ababa, Ethiopia (yimam2014@gmail.com)
Niguse Hagazi Country representative, CIFOR-ICRAF, Addis Ababa, Ethiopia (n.hagazi@cifor-icraf.org)
Amsale Shibeshi Regional programmes coordinator, PENHA, Addis Ababa, Ethiopia (amsale.shibeshi@penhasom.org)

Acknowledgements

The authors are very grateful to all those who participated in the processes that led to the production of this national review. Consultative meetings and workshops brought together participants from responsible agencies at Federal level and from all regional states of Ethiopia.

We would like to express our particular thanks to Ato Kebede Yimam, Director General of EFD, who played an excellent leadership role throughout the process and made substantial analytical contributions. We are grateful for his support to all of PENHA's work in Ethiopia.

We would also like to thank the many senior experts who made important contributions. Dr Motuma Tolera, Deputy Director General of Ethiopian Forestry Development (EFD) and Ato Tilaye Nigussie of the Forest Sector Transformation Unit (FSTU), who helped to facilitate consultative workshops and provided significant inputs. Aytenew Tatek of the Dutch Embassy in Addis Ababa also gave valuable insights at the outset.

This review benefited from participation in the 8th International Wildland Fire Conference 2023 (Portugal), an initiative of the Global Fire Monitoring Center (GFMC). The review aims to lay the foundations for the development of an effective national fire management system, as part of an ongoing programme jointly conducted by PENHA and CIFOR-ICRAF.

This work was made possible by financial support of the Ministry of Foreign Affairs of the Netherlands, and is part of the Fire-smart Landscape Governance Programme of Tropenbos International. The opinions and views expressed here are the sole responsibility of the authors and do not necessarily reflect those of Tropenbos International or the Ministry of Foreign Affairs of the Netherlands.

Assessing wildfires from the air, in the Bale Mountains. Photo: GFMC.

Table of Contents

Executive summary

Wildfires have been recognized as global environmental processes and ecosystems differ in their sensitivity and response to natural fires depending on their fire history and vegetation characteristics. Most wildfires particularly in the tropics are human induced. In the tropics, traditional use of fire for agriculture and rangeland management has shaped rural landscapes for long. In Ethiopia, it is widely believed that seasonal wildfires have become more frequent, widespread and impact forest resources and livelihoods. The absence of a national fire management system is seriously undermining the nation's green growth policies, strategies, and on-going initiatives (e.g., Reducing Emission from Deforestation and forest Degradation (REDD+), Afforestation and reforestation (A/R) and the Green Legacy Initiative (GLI)). If not addressed, this may even reverse the gains so far made.

This study was initiated to document forest fire management experiences in Ethiopia with emphasis on trends, responses and impacts in view of identifying gaps to be addressed and areas where support is needed to design an integrated, national forest fire management system. To this end, a comprehensive desk review and analysis of official documents and published and grey literature was conducted to understand traditional fire management practices and forest fire response experiences (actors, capacity, and coordination) to identify gaps in policies/strategies, institutional arrangements, coordination mechanisms, and capacity and thereby to make specific recommendations that will help in proposing an integrated national fire management system for Ethiopia.

The analysis was supplemented with key informant interviews and focus group discussions with a range of relevant stakeholders across sectors and levels. The review revealed that Ethiopia lacks proactive, evidence-based and coordinated response to manage forest fire incidences. A ban on traditional use of fire by pastoral communities is believed to have disrupted customary rangeland resource management practices and contributed to subsequent bush encroachment and rangeland degradation. Also, there are gaps in policy and legal frameworks; institutional arrangements, and organizational capacity (data, skills, and logistics), which all contribute to weak and less effective fire responses.

The review was complemented with a GIS-based assessment for the period 2001-2021 across Ethiopia of wildfire patterns, trends, and hotspot analysis, using Global Wildfire Information System (GWIS) open-source MODIS data. Between 2002 and 2019, the annual burned area ranged between 4.5 and 2.6 million hectares in forests, 1.4 and 3.1 million hectares in grass/shrub land, and 3.3 and 6.7 million hectares in cropland. In addition, the GWIS data showed a significantly declining trend in annual burned area and fire incidence overtime, though wildfires still affect many millions of hectares annually. Among the three land use types (crop, shrub, and forest), the rate of decrease is highest for forest land. The fire season (December to March) coincides with the dry period, with a peak in fire incidence between January and February. Fire hotspot areas are in the

northwest, west and southwest of the country. The trend in fire incidence across fire prone areas showed inter-annual variability.

This report recommends the development of a national fire management system. The establishment of this system should be based on a clearly articulated road map, milestones, and implementation arrangements in the short, medium, and long-term. The system should be evidence-based, must integrate fire management into landscape-level planning and management, and ensure multistakeholder and multilevel governance that supports and enables community-based fire management at local level. Building partnerships and cooperation with relevant national and international actors is clearly critical to strengthening Ethiopia's capacity for effective fire management.

Burned area in the Bale Mountains. Being able to collect data on areas burned is an essential component of fire management. Photo GFMC.

Chapter 1. Introduction

1.1. Ethiopia's forest-related strategies

Ethiopia has embarked on a journey to build a Climate Resilient Green Economy (CRGE), that set targets for building a carbon neutral economy and making Ethiopia a middle-income country by 2030. The CRGE strategy issued in 2011 had set emission reduction targets to be achieved by major economic sectors and identified forestry as having more than 50% of the abatement potential (FDRE, 2011). After completing the REDD+ readiness phase in 2017, Ethiopia started implementing its REDD+ strategy to reduce deforestation and forest degradation (D&D) through promoting participatory forest management (PFM) to better manage its natural forests (MEFCC, 2018a). Ethiopia's REDD+ program aims to increase the county's forest cover to 30% by 2030 through afforestation and reforestation initiatives (FDRE, 2017). In line with the targets, Ethiopia's Forest Sector Development Program (FSDP) which provided a 10-year implementation plan was launched in 2018 (MEFCC, 2018b). The FSDP aims at contributing towards achieving Ethiopia's national forestry targets and international commitments, like the Bonn Challenge (restoring an additional 15 million hectares of degraded land) and Ethiopia's Nationally Determined Contribution (NDC). The NDC updated in 2021 underlined the role of forests in ensuring Ethiopia's climate change mitigation ambition, where activities in land use change and forestry (LUCF) are expected to help reduce 84% of total projected emissions by 2030 (FDRE, 2021).

An emerging initiative with strong political support and leadership from the Prime Minister is the Green Legacy Initiative (GLI). The GLI is an ambitious, nationwide tree planting campaign that set target of planting 20 billion tree seedlings between 2019 and 2022. In August 2022, the Prime Minister reported that Ethiopia had planted 25 billion tree seedlings over the past four years surpassing the 20 billion target.[1] Similar reports were also aired by the Fana Broadcasting Corporation (a government affiliated media outlet) (FBC, 2022). But independent and field reports regarding numbers of seedlings planted, species composition and survival rates are lacking. The GLI is also a means to build up the natural resource base of the country and to better adapt to and mitigate climate change.

In relation to the role of forests in climate change adaptation, Ethiopia also issued a Climate Resilience Strategy (CRS) in 2015 by building on the CRGE strategy issued in 2011 (FDRE, 2015). The strategy identified that the forest sector was experiencing challenges regarding natural regeneration, forest fires, pests and diseases. Moreover, the CRS foresees the possible impacts of increasing climate change and disturbances like wildfire in the coming decades. In 2019, the government developed a comprehensive National Adaptation Plan (NAP) that outlines climate change related risks and hazards in the different economic sectors, and proposed strategies to better adapt to climate change

1. https://ethiopianmonitor.com/2022/08/14/green-legacy-tree-planting-campaign-concludes/

impacts (FDRE, 2019). The National Adaptation Plan identified wildfires (particularly in Gambella, Benishangul Gumuz and Oromia regions) as one of the major climate-related hazards in the country, affecting the livelihoods of significant numbers of people, and recommended that appropriate strategies be put in place (FDRE, 2019).

1.2. Wildfires in context

The definition of wildfire varies though it is generally understood as the unwanted burning of forests either by natural fire or man-made fire.[2] Natural wildfire includes burning of forest due to lightning or other causes, while human-induced wildfire results from the unauthorized burning practice of forests for various reasons and uses. An example is use of fire to smoke out wild bees while harvesting honey from forests and woodlands. Fire is commonly used as a cheap way of land clearing when converting forests and woodlands to agricultural plots. Fire can spread from one point to another in forested areas or other vegetation forms and even cross over to farmlands and settlements. By so doing fire can affect the whole or part of the landscape. There exist also prescribed fire that is practiced in and around parks, and in managing range lands and crop fields.

Communities living in areas where savannah grass and bushlands dominate, forest fires are used to control bush encroachment, to clear the land and make it ready for cultivation, and to encourage new growth. This happens as part of land management practice. The use of fire as an aid to hunting, controlling tsetse fly, and managing tick populations are also among the other causes of forest fires in the lowland areas. Agricultural burning is not limited to small-landholder farmers. It is also practiced in large-scale farms. Every year, just before the short rainy season, it is common to see deliberately set fires. Most of the fires are attended, managed, and controlled by the community members who set them while some are not. Despite inherent potential risks with fires, farmers consider it the cheapest and most common tool to clear land for farming. Sugarcane and cotton also provide considerable amounts of residues that are burned.

Wildfires are recognized as global environmental processes with impacts on the atmosphere and ecology. Fire influences ecosystem patterns and processes, vegetation distribution and structure, the carbon cycle, and climate at large (Bowman et al., 2009). Wildfires triggered naturally, play an important role in maintaining biodiversity and in regenerating forests, grasslands and shrublands across the world. In nature, fire regimes (frequency, seasonality, intensity and size) vary across ecoregions (Bailey, 2005), and are influenced by the complex interactions between climatic, weather and fuel properties (Rogers et al., 2020). The fire–climate–vegetation nexus is also affected by climate as it governs fire ecology through its influence on vegetation development and biomass production, and thus fuel availability (Nelson et al., 2012).

Globally, ecosystems differ in their sensitivity to natural fires depending on their fire history and vegetation characteristics. Vegetation responses to fire are broadly grouped

2. Encyclopedia of Environmental Health (Second Edition), 2019.

into three: (i) fire-dependent - where fire is essential and the species have evolved adaptations to respond positively to fire, (ii) fire-sensitive ecosystems - that do not evolve with fire as a significant recurring process and species that lack adaptations to respond to fire, and (iii) fire-independent, where fire plays little or no role (The Nature Conservancy, 2004). Evolutionary interactions between fire and ecosystems have since been disrupted by anthropogenic land use change and human-induced fire regimes (Moritz et al., 2014), resulting in the loss of ecosystem functions, biodiversity, livelihoods, and reduced resilience to fire (Xu et al., 2020). Thus, depending on the nature of ecosystems, fire can have ecologically beneficial impacts in some ecosystems, while impacting others negatively (Bailey, 2005).

In the tropics, most wildfires are believed to be caused by human activity (WWF, 2020) as fire is commonly used as a tool for land clearing and conversion and swidden agriculture (shifting cultivation) is practised in addition to arson (CBD, 2001). In the past few decades, uncontrolled wildfires have been increasingly impacting large tracts of forests, aggravating the already high rates of deforestation particularly in the tropics (FAO, 2012). The frequency, intensity and impacts of wildfires are further compounded by the ever-increasing global temperature and extended drought periods due to climate change, particularly in tropical and sub-tropical forests, woodlands and savannas (Jolly et al., 2015). Estimates show that in the tropics annually 76 million hectares are affected by forest fires (AfCo, 2022). As per the Global Wildfire Information System and reported in AfCo (2022), between 2002-2019, globally on average 8.9 to 9.2 million ha of land is burned annually, depending on the source. Africa, South America, and Oceania respectively contribute to 4.01 million ha (43.5%), 2.35 million ha (25.5%), and 1.76 million ha (19.2%) indicating that these three Regions account for over 88% of burned areas worldwide.

Wildfires contribute to global greenhouse gas (GHG) emissions and negatively affect public health, economic activity, and provision of ecosystem services (Tyukavina et al., 2022). They significantly and adversely affect societies, with dramatic consequences on living conditions of local communities and on their trust in governmental authorities (IUFRO, 2018). Environmental costs of wildfires though not properly quantified (Doerr and Santin, 2016) range from GHGs emissions to loss of forests and biodiversity and subsequent reduction in capacity to provide environmental services (IUFRO, 2018).

Wildfires are shaped by diverse social, economic and natural drivers. The complex interactions among these also influence the fire environment, the response of different landscapes to fires, and their impacts on communities across landscapes (IUFRO, 2018). Regional differences in sensitivity to and capacity to respond to future fire are expected, although the magnitude and direction of these changes remain uncertain (Liu et al., 2019; Walker et al., 2019). Fire seasons are getting longer, and extreme fire seasons have become more common. Fire seasons have expanded globally by 19% on average (WWF, 2020). This increase is particularly severe in East Africa and Brazil, with forests and savannas in South America experiencing an average of one month longer fire seasons

(WWF, 2020). But information regarding wildfire in Ethiopia with emphasis on trends and impacts are scanty to be able to devise a national forest fire management system.

1.3 Objectives and methods

This study is part of the Pastoral and Environmental Network in the Horn of Africa (PENHA)-Ethiopia program that addresses forests and woodlands with a primary, but not exclusive, focus on the drylands.

The PENHA-Ethiopia program is part of a set of activities PENHA is conducting in collaboration with Tropenbos International (TBI), a leading Dutch NGO, funded by the Ministry of Foreign Affairs of the Netherlands under the Working Landscapes programme. Knowledge generation and management under the program aims to support national policy development efforts, primarily by working closely with the Ethiopian Forestry Development (EFD) of the Ministry of Agriculture (MoA) as well as with national and international research institutions and CSOs working at national, sub-national and landscape levels. The objectives of this study were to:

- document experiences in wildfire prevention, response and post-fire management of impacted landscapes in Ethiopia with emphasis on challenges and gaps.
- Identify existing forest fire management practices focusing on capacity, institutional arrangements, policy and legal frameworks in view of putting in place an improved fire management system.
- Provide recommendations on how an integrated forest fire prevention and management system can be established in Ethiopia and address prevailing gaps and challenges.

The study used a combination of methods. A desk study involved a comprehensive review and in-depth analysis of available literature regarding forest fires in Ethiopia, supplemented with key informant interviews with relevant experts, using a structured questionnaire (See Annex 1). Respondents were asked to respond to set of questions in a structured questionnaire regarding forest fire causes, incidences, capacities, responses and gaps in their respective regions (see Annex for the questionnaire).

The information so gathered was analysed and findings were shared, and comments were solicited in a workshop organized to validate findings, which brought together government officials and other experts from federal, regional and civil society organizations.

To better document forest fire occurrence and trends overtime, MODIS data was gathered and analysed to identify hotspot areas and districts that should get prior attention. This task involved:

- Collection/generation of data on wildfire patterns and trends using forest fire statistics.

- Collating MODIS data on fire trends from 2000 to 2020 and presenting remote sensing data on fire frequencies and burned areas using MODIS products.
- Identifying current fire hotspots in Ethiopia and predict future fire hotspots by 2030.
- Summarizing and presenting findings in ways that can be understood by non-technical experts and policy makers
- Proposing the need for ground validation data when using MODIS free databases as MODIS usually underestimates small fires.

The results of this study are expected to inform the formulation and implementation of a national forests management strategy, and to serve as springboards for further studies on forest fires in Ethiopia. Data generated by the study would also form the basis for the establishment of a national forest fire database that could in turn be part of efforts to build a national forest information system in Ethiopia. This will enable stakeholders to gain a better understanding of fire dynamics and emissions and to identify fire hotspots in order to propose tailored actions to reduce future fire risks.

1.4 Structure of the review

The review is organised under five chapters. Chapter 1 introduced the topic and the tasks. In Chapter 2 the analysis of patterns and trends of wildfire in Ethiopia using MODIS Data are described. Chapter 3 presents findings of the literature review on wildfire management in Ethiopia with emphasis on fire management practices as well as gaps and challenges in managing wildfires. Relevant international practices are summarised in Chapter 4. Finally, specific actions are recommended in Chapter 5 to be considered in building a national wildfire management system in Ethiopia.

Chapter 2. Analysis of wildfire patterns and trends using MODIS data

2.1 Why MODIS data and how was the data analysed?

Though wildfires occur frequently, information on their frequency, intensity and impacts are scanty. There are no official national fire statistics to analyze the trend of wildfire in Ethiopia. Estimates of burnt areas have so far relied on simple assumptions. A consistent, reliable, large-scale characterization of the spatial and temporal distribution of burned areas is required to assess environmental and economic impacts of wildfires and to support the development of effective fire management system. Remote sensing data on active fires globally provides an important tool to achieve this goal while removing inconsistencies associated with national fire reporting. Despite the country's long-time experience of being exposed to wildfires, information on the type and extent of burned areas are limited, and these are in the form reports and workshop proceedings.

The reports show that fires continue to affect forests, shrubland, and grasslands. This study was proposed to contribute towards filling this knowledge gap. Being the first study to do a national assessment of fire activity in different land cover types in Ethiopia, it attempted to identify spatial patterns in burning from 2002 to 2021. It also demonstrated the use of MODIS data in generating fire-related information at varying temporal and spatial scales. The MODIS fire data products and land cover data sets, and the methodology used in this analysis are described in the methods section. In the result section, national- to district-scale fire occurrences are presented. The results cover the spatial and temporal (inter - and inter-annual) aspects of fire. The monthly time series of burned areas were analyzed to investigate the seasonal and inter-annual variations in burning by land cover. The fire patterns by the land cover for selected major hot spot districts are presented and explanations provided for the observed seasonal and inter-annual variations. Finally, conclusions and recommendations are provided. All supplementary summary tables, charts, and maps have been compiled and some attached to this study report as annexes.

2.2 Data types and analysis

2.2.1 Data types

The table opposite presents the types and sources of data used for the study.

Statistical estimates of Global Wildfire Information System: The Global Wildfire Information System (GWIS) provides a comprehensive assessment of fire regimes and fire effects at global level to provide information and to support operational wildfire management at all levels. One of its components supports the generation of a country profile. The authors used this to generate information for the period 2002 to 2019 for Ethiopia. The GWIS derived these data from the MCD64A1 burned area product. The

Table 1. Types and sources of data used to examine forest fire trend in Ethiopia

Type of required data	Sources of data and area extent
Annual Statistics for Ethiopia	Global Wildfire Information System statistical estimates https://gwis.jrc.ec.europa.eu/apps/gwis.statistics/estimates
Annual burned area (2000 – 2020)	MCD64A1.061 MODIS Burned Area Monthly Global 500m https://lpdaac.usgs.gov/products/mcd64a1v061/
Current fire hotspots	Time-series Annual burnet area / Ethiopia, a process in this study
Future fire hotspots	Time-series Annual burnet area/ Ethiopia, a process in this study
Validation data	Moderate satellite imagery (Landsat 4,7,8, and 9, and sentinel 2 images) for selected demonstration site(s)
Baseline data	Administration boundary [district] / Open layer River basins of Ethiopia / Open layer Ethiopia Protected areas of Ethiopia / IUCN

study used the following data which were available in tabular format (csv): yearly burned area and number of fires, yearly burned area by seasons, yearly burned area by landcover, average monthly burned area by landcover, average monthly burned area by seasons and number of fires, monthly burned area by landcover, monthly burned area by seasons and number of fires, average monthly fire size and number of fires, and average monthly fire size distribution.

MCD64A1.061 MODIS burned area monthly global 500 m: The Terra and Aqua combined MCD64A1 Version 6 Burned Area data product is a monthly, global gridded 500 m product containing per-pixel burned area and hence provides quality information. The MCD64A1 burned-area mapping approach employs 500m MODIS Surface Reflectance imagery coupled with one km MODIS active fire observations. The algorithm uses a burn-sensitive vegetation index (VI) to create dynamic thresholds that are applied to the composite data. The VI is derived from MODIS shortwave infrared atmospherically corrected surface reflectance bands 5 and 7 with a measure of temporal texture. The algorithm identifies the date of burn for the 500 m grid cells within each individual MODIS tile. The date is encoded in a single data layer as the ordinal day of the calendar year on which the burn occurred, with values assigned to unburned land pixels and additional special values reserved for missing data and water grid cells.

The MCD64A1 dataset was accessed for this study through the Google Earth Engine (GEE) environment. GEE is a free cloud-computing platform for satellite data processing, with several data catalogs at different resolutions (notably Landsat, Sentinel-2 and MODIS) and with capabilities for planetary-scale analysis (https://earthengine.google.com).

Recently, the number of studies that used GEE has increased. Most of the studies are in the areas of vegetation mapping and monitoring, land-cover mapping, and applications in the fields of agriculture. But published papers or on-going studies that used satellite images and employed GEE to examine long term trends of forest fires in Ethiopia are not known to the authors. GEE combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities. MCD64A1 is accessible in GEE. And Earth Engine is now available for commercial use and remains free for academic and research use.

Medium resolution images: Reference data were required to evaluate the results of burned area analysis. To validate the MODIS-based burned area mapping results, the multi-temporal Landsat 8 and Sentinel 2 images were acquired and pre-processed for selected sites.

Baseline data: The baseline data were required to aggregate and disaggregate the spatial and temporal analysis results. The baseline data include spatial data for districts, districts adjoining the neighboring countries, and protected areas. This was undertaken to also demonstrate the application of remote seining for forest management.

2.2.2 Data pre-processing

The data pre-processing procedure consisted of pre-processing MODIS Burn-Area and extracting the burned area for the country from the pre-processed global data. The MCD64A1 dataset was acquired for the period 2001 to 2021. The MCD64A1 data were pre-processed in GEE environment. The pre-processing of the MCD64A1 includes filtering data for each month of the analysis year. The date is encoded in a single data layer as the ordinal day of the calendar year on which the burn occurred. A mask layer was created for each month using the QA and uncertainty layer. Using the mask layer, the layer was updated for further processing. The output of the masked layer covers pixels. The masked layer variable only shows pixels that, in QA band, have "bit 0 value 1, bit 1 value 1, and bit 3 value 1". This corresponds to a pixel where the grid cell was land grid cell, relabeled, and used sufficient valid data. The masked layer was furthermore pre-processed using the 'Uncertainly layer.'

Only pixels with uncertainty less than or equal to 5% were used for the analysis. Each month's pre-processed data was aggregated to create the annual burn-area layer. For each year, the burn layer was created using the minimum and maximum algorithm. The result of the aggregation was a single layer with two bands for minimum and maximum burn date. The image collection of each analysis year was converted to a band. This resulted in 12 bands per image per analysis year. This was required to facilitate the reporting of the monthly data to a drive for analysis in a GIS environment. Finally, this layer was clipped to the country layer and exported to derive further prepossessing.

Table 2: Sample data on burned area in hectares in Quara District of Amhara Region

Year	Year Analysis	Month	Landcover	Area_Ha
2001	2002	10	Crop	900
2001	2002	10	Forest	0
2001	2002	10	Herbaceous/Shrub	800
2001	2002	11	Crop	66800
2001	2002	11	Forest	0
2001	2002	11	Herbaceous/Shrub	12350
2001	2002	12	Crop	124000
2001	2002	12	Forest	400
2001	2002	12	Herbaceous/Shrub	44725
2002	2002	1	Crop	21050
2002	2002	1	Forest	25
2002	2002	1	Herbaceous/Shrub	9500
2002	2002	2	Crop	21350
2002	2002	2	Forest	400
2002	2002	2	Herbaceous/Shrub	10100
2002	2002	3	Crop	21675
2002	2002	3	Herbaceous/Shrub	9500
2002	2002	4	Crop	11400
2002	2002	4	Forest	175
2002	2002	4	Herbaceous/Shrub	10525
2002	2002	5	Crop	6325
2002	2002	5	Forest	0
2002	2002	5	Herbaceous/Shrub	5325
2002	2002	6	Crop	150
2002	2002	6	Forest	0
2002	2002	6	Herbaceous/Shrub	25
2002	2002	7	Crop	0
2002	2002	7	Forest	0
2002	2002	7	Herbaceous/Shrub	0
2002	2002	8	Crop	0
2002	2002	8	Forest	0
2002	2002	8	Herbaceous/Shrub	0
2002	2002	9	Crop	0
2002	2002	9	Forest	0
2002	2002	9	Herbaceous/Shrub	0

Software for pre-possessing and analysis: The MODIS fire products were acquired in GEE environment. The MODIS products for each were first filtered to cover both the spatial and temporal resolution/coverage for Ethiopia for the period 2001 to 2021. The GEE was used to derive monthly burned data for the whole of Ethiopia. For each analysis year, each monthly data was converted into a band to create an image with multiple bands. Each band of an image represents one month of burned data. This was required to facilitate the exporting of the monthly burned data into the derive. Each monthly burned area data was exported to derive for further prepossessing. The analysis was conducted using R. The analysis in R required library packages including raster, rts, terra, reshape2, and fields.

Baseline data: The analysis requires aggregating spatial data including national boundary and districts of the country. These layers were used as input for the aggregation of the burned area, which is available at the country level. The analysis primarily used the burned area data. These layers were created for each land use category: Crop, Forest, and Shrub/Herbaceous. The burned areas analysis considered the occurrence of the fire in a pixel independent of the number of months within the analysis period (one year). The analysis period crosses two calendar years: starting from October to September of the next year. This is aimed to address the Ethiopian seasons of the year. An example of burned area information for 2020 covers the period from October 2019 to September 2020. The preprocessing results in the burned area of each period by land cover types were inputs for the fire occurrence and burn trend analysis.

Monthly burned area data: This study used the monthly burned area data to create the yearly burned area data for the period 2001 to 2022. The yearly burned area data was split by land cover types using the MODIS land cover layer. This analysis produced three yearly burned area layers for cropland, shrub/herbaceous vegetated land, and forest-dominated land.

District temporal burned area by land cover: The pre-processing of data includes aggregating the yearly burned area by district, year, month, and land cover. The yearly trend of burn is presented by district and land cover. The table below shows, as a sample, the burned area information of selected districts. This table presented in this section is only to demonstrate the available raw data for stakeholders for their use. Readers can request PENHA for the data. AS this set contains over 65000 raw of records, it was too large to be part of this document.

2.2.3 Data analysis

Spatio-temporal analysis of burned areas: The spatial distribution of fire occurrence was analysed using the time-series annual burn-area data. The number of years with burned area value at each pixel were counted. The result of this analysis was a single layer with values between 1 and 20. The value 20 corresponds to the range of the analysis period. The next step reclassified the values into classes: low, medium, high, and very high occurrences. The result was presented as a map to show the spatial distribution of fire occurrence. The fire occurrence layer and the baseline data were used to estimate the burned area extent in hectares at national and district levels.

Fire trends: The estimated area affected by fire is produced by country, region, and zone levels for each year from 2001 to 2021. The R terra package was used to generate this time series information. The result of the analysis is presented as graph.

Hot spot area analysis: The result of the analysis above was used to identify current fire hotspots in Ethiopia. The most recent years with a higher number of occurrences were selected and grouped as hot-spot areas. Those areas where the historical trend of fire occurrences declined were masked out. The historical trend was classified into three periods: 2001-2007, 2008-2014, and 2015-2021.

Prediction of the future hotspot areas: The QGIS MODUS was used to predict the 2030 future fire occurrences. As input data, the three periods of fire data as well as elevation data were used. The first two periods were used to predict the third period. The result of third-period hot-spot data was used to validate the prediction. The result of the validation was used to decide on the use of the model for future prediction. The hot spot analysis was repeated until the validation result was acceptable. Once the validation was acceptable, the 2030 prediction of the hot-spot analysis was finalized at national levels using the first and the second hot-spot layers. The result of the predicted hot-spot analysis was presented as a map, and the estimated future predicted hot-spot areas were presented as a graph.

2.2.4. Accuracy assessment

Accuracy assessment of the burn-area data was done for selected years and selected areas. The areas were selected based on historical reports. The criteria for the selection were: a) areas known for forest fire, b) areas affected by fires but having patches with varying areas (small to large), c) availability of images with less cloud effect. Images before and after the fire were acquired for the selected site. The images were classified into fire-affected or non-fire-affected areas. The result of the burn area mapping was compared with the corresponding MODIS-based burn-area map produced by this study. The error matrix was not calculated and presented as a contingency table due to the small number of reference data. Due to time constraints, the reference data was restricted to smaller areas. Therefore, the relationship between the two types of maps was not analyzed using the contingency table.

2.3. Results

The results of this exercise contribute to responding to following key questions that policy makers and field level workers engaged in fire management.

- Where has been fire taking place frequently?
- When did fire frequently take place?
  - o Months when the fire onset is more frequent
  - o The length of the fire period

- Which types of land cover have been impacted by fire more?
- What was the trend of fire in Ethiopia over the last two decades?
- Which areas in the country are fire hotspots?

As the study produced fire information on burned areas at three levels – national, river basin and district levels. But the results in this report are presented only for the two – national and district levels. The national level national information will be useful for policy makers while district level information will be used by field level actors.

2.3.1 Data on fire incidences

To bridge the knowledge gap on fire trends in Ethiopia, recent trends in burned areas have been produced at national scale from satellite observations with reasonable accuracy. Table 3 presents burned area in Ethiopia from 2012 to 2021. Table 4 shows the burned area in Ethiopia from 2002 to 2019 using the MODIS-based system. Both tables showed a decline in burned area over time.

Table 3: GWIS Annual Statistics on burned area in Ethiopia from 2012 to 2021

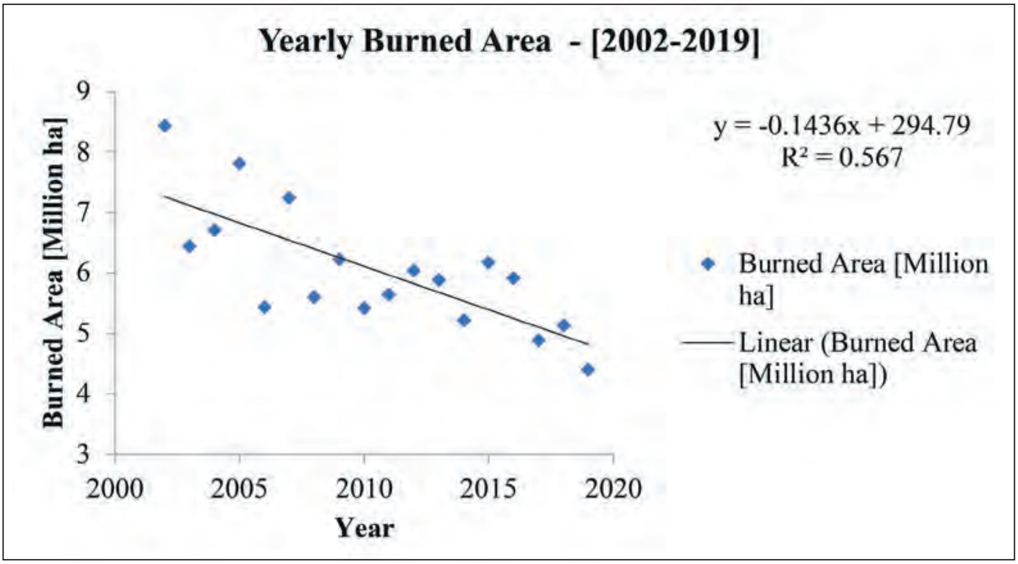
Year	Burned area (ha)	Number of fires
2012	8,022,747	11,798
2013	7,528,344	10,702
2014	5,059,910	10,201
2015	8,383,699	13,936
2016	9,389,997	13,724
2017	4,265,465	10,012
2018	4,440,413	10,636
2019	4,491,167	10,214
2020	6,549,651	15,151
2021	3,423,737	7,920
2022	4,433,225	9,981

Table 4: Yearly burned area and number of fires from 2002 and 2019, using the MODIS-based system

Year	Burned area ha	Number of fires
2002	8,441,424	13,997
2003	6,450,637	11,355
2004	6,722,931	11,113
2005	7,816,359	11,372
2006	5,441,914	9448
2007	7,248,974	12,803
2008	5,608,596	10,090
2009	6,230,504	10,078
2010	5,419,781	10,506
2011	5,647,751	9384
2012	6,048,624	10,213
2013	5,891,773	10,400
2014	5,225,775	9662
2015	6,178,750	12,024
2016	5,921,633	11,817
2017	4,895,651	9020
2018	5,145,019	10,830
2019	4,408,676	8624

Figure 1 shows the significant decrease in burned area from 2002 to 2019. The rate of decrease was 143,000 hectares per annum ($R^2 = 0.57$, $P < 0.001$).

Figure 1: Yearly burned area from 2002 to 2019

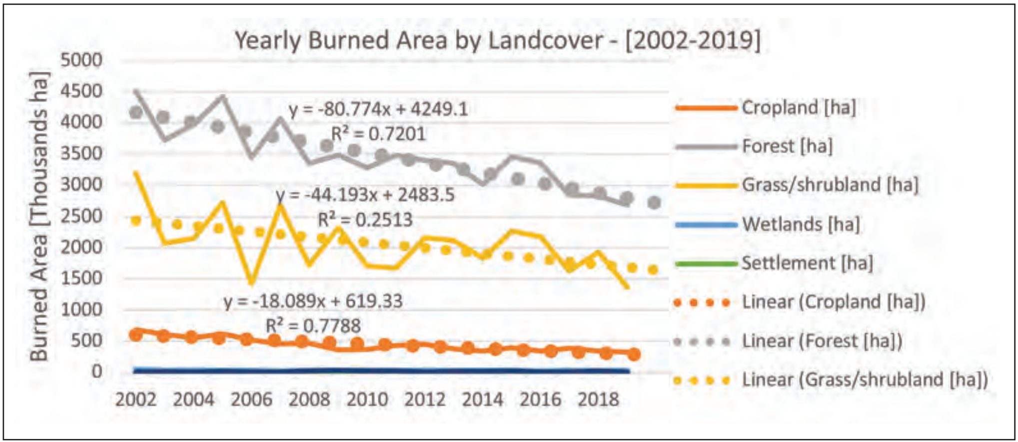


The GWIS data showed a significant decrease in burned area over time, but the rate of decrease for forest was the highest as compared to rate of decline for croplands and for shrub/grass lands. The rates of the burned area decrease per annum were 80,000 ha, 44,000 ha, and 18,000 ha for forest, crop, and grasslands, respectively. Between 2002 and 2019, the annual burned area in forests, in grass/shrub land, and in cropland ranged respectively between 4.5 and 2.6 million hectares, 3.1 to 1.4 million hectares and 6.7 to 3.25 million hectares. The total average of burned area per annum during the study period was 6.04 million ha. The year 2002 recorded the highest burned area in forest land, which was 4.5 million ha, followed by 2005 with 4.4 million hectares, and 2007 with 4.1 million hectares. The year 2019 was the least with 2.8 million hectares followed by 2018 (2.8 million hectares). The year 2002 recorded the highest burned area in shrub land: 3.2 million hectares burned area followed by 2005 with 2.71 million hectares and 2007 with 2.67 million hectares. The year 2019 was the least with 1.36 million hectares followed by 2006 (1.42 million hectares).

Table 5: Yearly burned area by land cover, 2002-2019

Year	Cropland [1000 ha]	Forest [1000 ha]	Grass/ shrubland [1000 ha]	Wetlands [1000 ha]	Settlement [1000 ha]	Other [1000 ha]	Total burned area [1000 ha]
2002	685.74	4506.75	3189.91	49.47	0.30	9.23	8441.40
2003	609.07	3721.10	2075.66	33.09	0.08	11.61	6450.61
2004	552.89	3976.48	2153.45	35.76	0.19	4.14	6722.91
2005	621.15	4426.60	2718.45	35.26	0.28	14.59	7816.33
2006	523.93	3450.52	1424.71	33.46	0.15	9.12	5441.89
2007	462.89	4072.39	2675.71	27.49	0.15	10.32	7248.95
2008	472.29	3347.96	1725.01	36.42	0.84	26.06	5608.58
2009	361.69	3481.33	2318.54	36.04	0.28	32.60	6230.48
2010	374.02	3276.54	1710.31	33.03	0.13	25.73	5419.76
2011	429.72	3486.91	1670.28	35.20	0.26	25.37	5647.74
2012	450.67	3394.89	2161.56	31.49	0.13	9.87	6048.61
2013	377.47	3347.81	2120.63	33.01	0.08	12.75	5891.75
2014	343.66	3010.13	1831.10	29.30	0.00	11.56	5225.75
2015	393.34	3455.50	2269.11	33.76	0.08	26.93	6178.72
2016	342.18	3361.49	2179.60	27.56	0.13	10.66	5921.62
2017	388.70	2844.48	1625.78	33.53	0.21	2.94	4895.64
2018	339.82	2829.35	1928.36	26.89	0.04	20.54	5145.00
2019	325.44	2682.03	1367.52	30.86	0.06	2.74	4408.65

Figure 2: Trends of the yearly burned area by land cover between 2002 and 2019



The temporal changes of burned area were investigated on monthly basis from 2001-2019. As shown in the figure, there was a large inter-annual variation in average monthly patterns of fire occurrence. The most significant being January, which had the highest burned area (24%) followed by February (23%) and December (18%). For all years combined, a total of 80% of fire occurred from December to March and this corresponds largely to the dry season. April, as onset of the wet season, is less impacted with only less than 1% each. October and November account for 12% of the total annual burned area. This would be because in dry season, the weather is warmer and drier, which favors the occurrence of fires and their spread.

Table 6: Average monthly burned area, seasonality and number of fires, 2002-2019

Month	Burned area [ha]	Number of Fires	Fire season	%
Oct	125,404	511	outside fire season	12
Nov	622,386	1200	outside fire season	
Dec	1,097,653	1788	fire season	80
Jan	1,476,738	2088	fire season	
Feb	1,405,264	2164	fire season	
Mar	856,471	1497	fire season	
Apr	316,988	667	outside fire season	8
May	52,122	238	outside fire season	
Jun	19,477	134	outside fire season	
Jul	10,275	88	outside fire season	
Aug	18,449	121	outside fire season	
Sep	40,149	213	outside fire season	
Average annual	604,1376	10708		

Figure 3: Average monthly burned area seasonality, 2002-2019

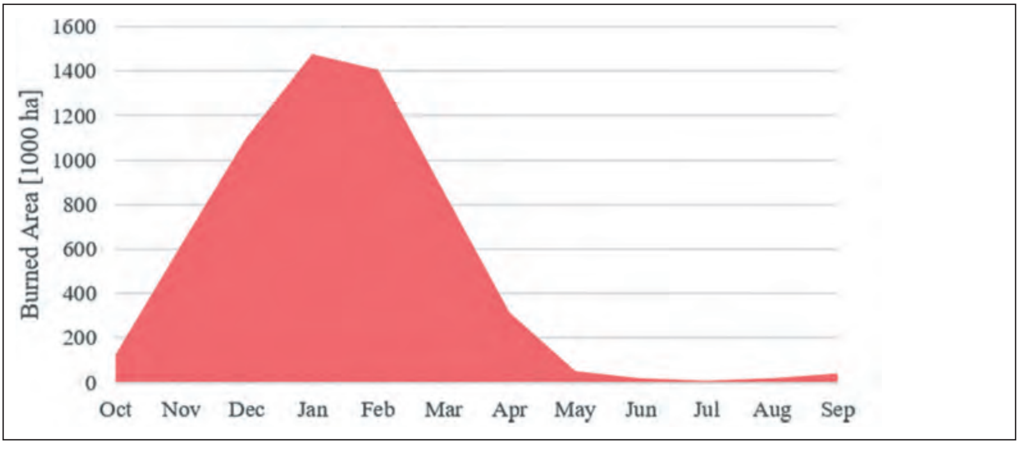


Figure 3 shows the monthly burned area for each year from 2001 to 2019. As the table shows, December to April (light red) are the months with burn activity. The rest of the months are less categorized as months having less impact on burned area.

Table 7: Yearly burned area seasonality in millions of hectares, 2002-2019

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2002	0.36	1.20	1.45	1.60	1.83	1.14	0.52	0.10	0.03	0.01	0.05	0.16	8.44
2003	0.18	0.68	1.06	1.37	1.72	0.84	0.39	0.10	0.01	0.03	0.01	0.06	6.45
2004	0.27	0.61	1.07	1.12	1.65	1.24	0.61	0.10	0.02	0.02	0.00	0.01	6.72
2005	0.06	0.89	1.96	1.81	1.59	0.87	0.47	0.12	0.01	0.01	0.01	0.01	7.82
2006	0.07	0.39	0.95	1.49	1.26	0.78	0.44	0.03	0.00	0.00	0.00	0.03	5.44
2007	0.15	0.63	1.83	1.15	1.48	1.47	0.44	0.05	0.01	0.01	0.01	0.02	7.25
2008	0.13	0.54	1.18	1.19	1.49	0.83	0.18	0.04	0.01	0.00	0.00	0.00	5.61
2009	0.20	1.43	0.79	1.34	1.04	1.04	0.18	0.07	0.07	0.02	0.02	0.03	6.23
2010	0.09	0.72	1.08	1.26	0.98	0.78	0.34	0.05	0.01	0.01	0.04	0.07	5.42
2011	0.12	0.49	1.07	1.13	1.55	0.84	0.36	0.04	0.04	0.00	0.00	0.00	5.65
2012	0.08	0.26	0.81	1.53	2.09	0.83	0.41	0.04	0.00	0.00	0.00	0.01	6.05
2013	0.03	0.31	1.05	1.67	1.33	0.88	0.48	0.06	0.01	0.03	0.04	0.01	5.89
2014	0.03	0.20	0.96	1.72	1.37	0.77	0.10	0.02	0.02	0.01	0.01	0.00	5.23
2015	0.17	0.75	0.86	1.63	1.49	0.86	0.23	0.03	0.03	0.01	0.05	0.09	6.18
2016	0.08	1.03	1.18	1.15	1.58	0.50	0.18	0.03	0.01	0.01	0.06	0.11	5.92
2017	0.06	0.40	1.18	2.03	0.75	0.35	0.07	0.01	0.03	0.01	0.00	0.00	4.90
2018	0.15	0.45	0.95	1.21	1.35	0.71	0.16	0.01	0.01	0.01	0.02	0.11	5.15
2019	0.02	0.20	0.34	2.19	0.75	0.71	0.14	0.04	0.01	0.01	0.00	0.00	4.41

With increase in fire size, the number of occurrences of the corresponding burned area size decreases. In other words, large number of fires impacted smaller patches areas/size in Ethiopia. For instance, burned areas with approximately 30 hectares occurred over 26000 times.

Fire size distribution refers to the distribution of burned area. It is usually calculated by analysing the frequency of fires in different size (area, ha) classes. For instance, fire size distribution shows that 85000 burn occurrences had an area covering less than 128 hectares, while 23 fire occurrences had an area more than 2 million hectares.

The importance of studying fire size distribution and frequency of fire occurrence contribution to total burned area cannot be overstated. This distribution is essential in analysing the magnitude and impact of a fire event on the environment. As fire destroys millions of hectares of forest and other natural habitats across the globe every year, is imperative to study the nature and characteristics of these fires to create effective mitigation measures. One such characteristic is the fire size distribution and its percentage

Table 8: Area extent of burned areas and their number

Fire Size [ha]	Number of fires	Total burned area [%]
32	26,668	3
64	33,200	5
128	25,852	10
256	20,912	17
512	13,530	26
1024	7760	36
2048	4014	47
4096	2061	57
8192	1077	67
16,384	462	74
32,768	208	80
65,536	103	85
131,072	47	90
262,144	36	95
524,288	3	95
1,048,576	20	97
2,097,152	14	99
4,194,304	6	100
16,777,216	3	100

Figure 4: Fire size distribution and % contribution to total burned area, 2002-2019

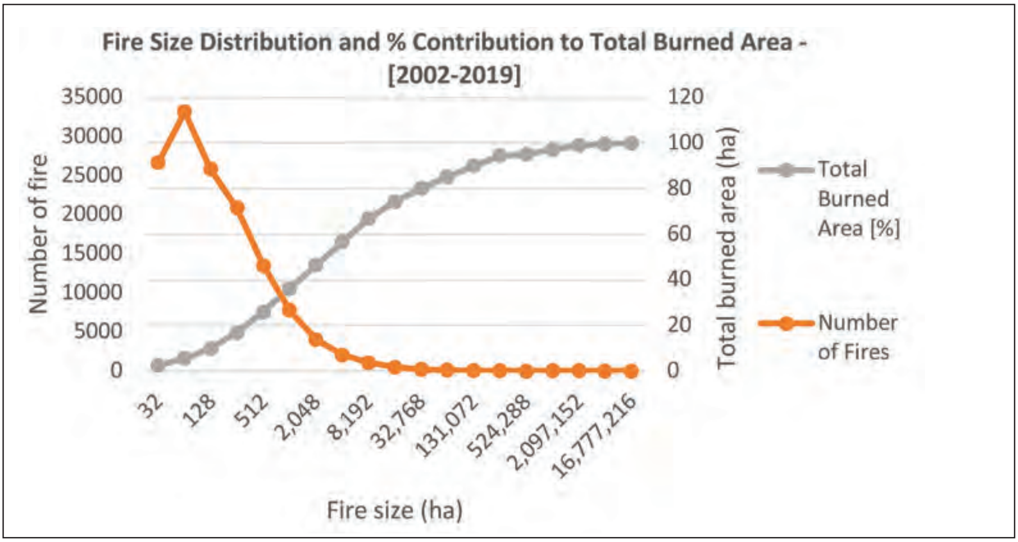


Table 9. The case of Quara District in Amhara Regional State

District	Year	Year of analysis	Month	Land cover	Area (Ha)
Quara	2001	2002	10	Crop	900
Quara	2001	2002	10	Forest	0
Quara	2001	2002	10	Herbacious/Shrub	800
Quara	2001	2002	11	Crop	66800
Quara	2001	2002	11	Forest	0
Quara	2001	2002	11	Herbacious/Shrub	12350
Quara	2001	2002	12	Crop	124000
Quara	2001	2002	12	Forest	400
Quara	2001	2002	12	Herbacious/Shrub	44725
Quara	2002	2002	1	Crop	21050
Quara	2002	2002	1	Forest	25
Quara	2002	2002	1	Herbacious/Shrub	9500
Quara	2002	2002	2	Crop	21350
Quara	2002	2002	2	Forest	400
Quara	2002	2002	2	Herbacious/Shrub	10100
Quara	2002	2002	3	Crop	21675
Quara	2002	2002	3	Forest	0
Quara	2002	2002	3	Herbacious/Shrub	9500
Quara	2002	2002	4	Crop	11400
Quara	2002	2002	4	Forest	175
Quara	2002	2002	4	Herbacious/Shrub	10525
Quara	2002	2002	5	Crop	6325
Quara	2002	2002	5	Forest	0

contribution to the total area burned. For instance, fire size distribution data can help land managers to develop effective management plans for different regions with varying fire regimes. Additionally, the frequency of occurrence contribution to total burned area can help policymakers develop appropriate land management policies to reduce the risk of massive fires. If the data show that a few large fires contribute a significant percentage of the total area burned, policymakers can redirect resources towards mitigating fire risks in those areas. For instance, they can develop policies that encourage communities in high-risk areas to thin vegetation and create firebreak to reduce the build up of fuel.

MODIS-Based burned area data: One of the objectives of this study is to derive raw data that can be used by users for answering burned area related questions at defined geographic extent. Districts were selected for deriving the burned area data as they represent decision making centers in wildfire management at local level. The data produced helped identify the regions and districts, which are more prone to fire, and this is presented below. Table 9 contains detailed burned area that was extracted from the MODIS product for selected districts for demonstration purposes. It contains aggregated data of the burned area in hectares by district, year, month, and land cover. Users can use such data that is available for each district as supplementary data, for further analysis. For demonstration of the available raw data on burned area data (ha) by district, year, month, and land cover, only one district's information for 2001 and 2002 is presented in Table 9.

2.3.2. Fire occurrence at national level

The burned area occurrence maps show the spatial distribution of burned areas at the national level. The fire occurrence values range from 0 to 20. The values 0 and 20 correspond to the two extreme cases: the area that never experienced fire incidence and areas with fire incidences occurring every year during the analysis period. Areas with zero occurrences were masked out (white in the maps). The burn occurrence ranges from 1 to 20. Areas with the highest burn occurrence are highlighted as dark red in the figure. Areas with relatively low burn occurrence are yellow highlighted.

Spatial distribution of fire occurrence independent of land cover types: The burn occurrence map shows the spatial distribution of the burn-affected areas independent of the land cover types based on the data from 2001 to 2021. The figure below shows the spatial distribution of the major land cover types in 2020/21 in the major basins of the country.

Bamboo forest assigned to agricultural investment in Benishangul Gumuz, Ethiopia. Photo by W. Gabriel Gebremedhin.

Figure 5: Land cover of Ethiopia in 2021 (Based on MODIS data)

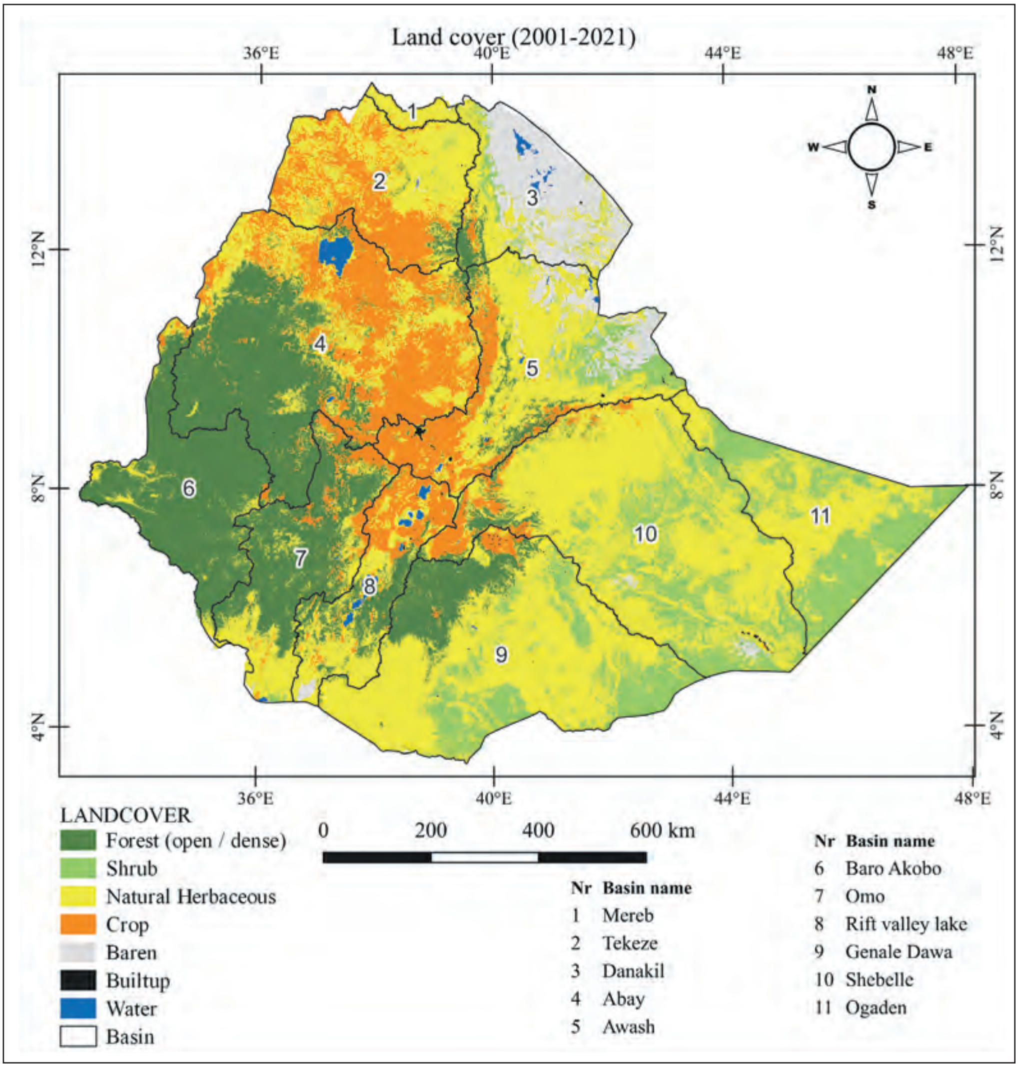
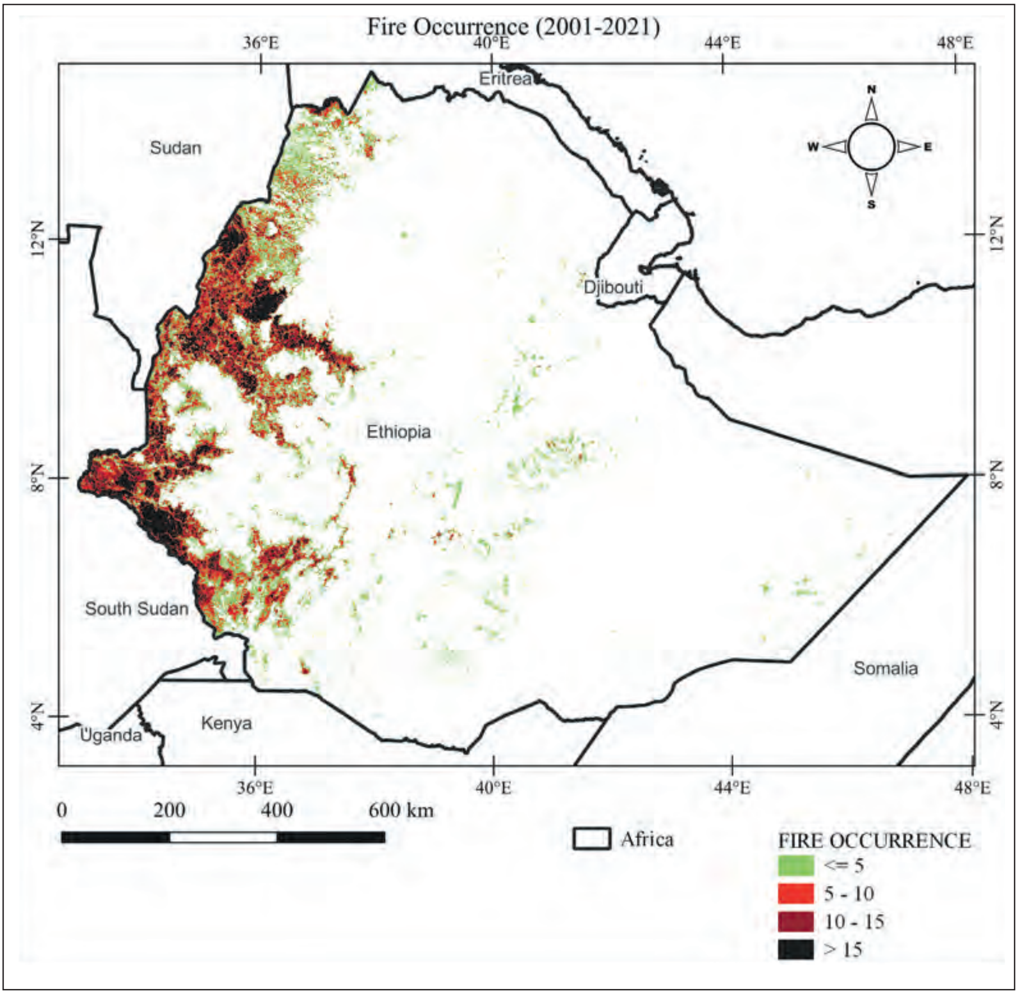


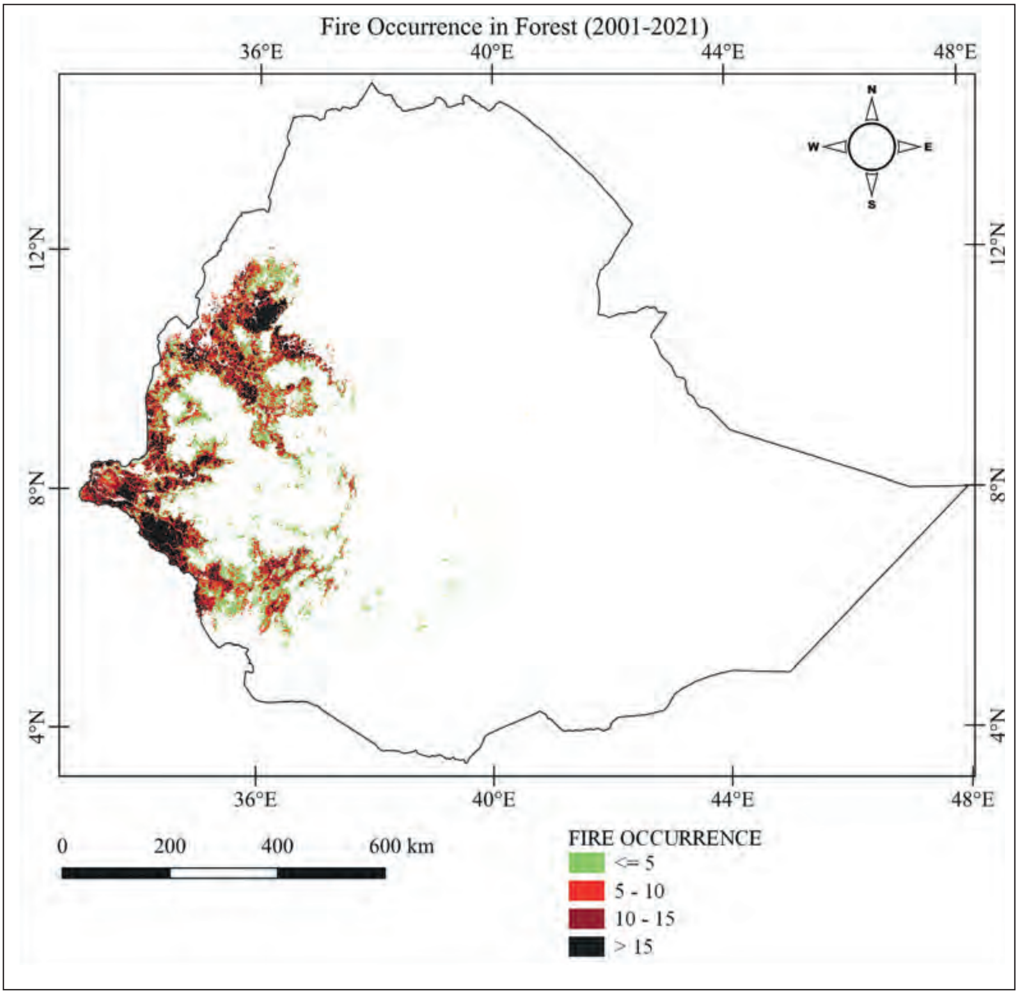
Figure 6: National level spatial distribution of fire occurrence independent of the land cover types



The figure above is the fire occurrences map from 2001 to 2021. The dark red colour represents areas with over 15 years of occurrences, whereas the green highlighted areas experienced fire for less than six years.

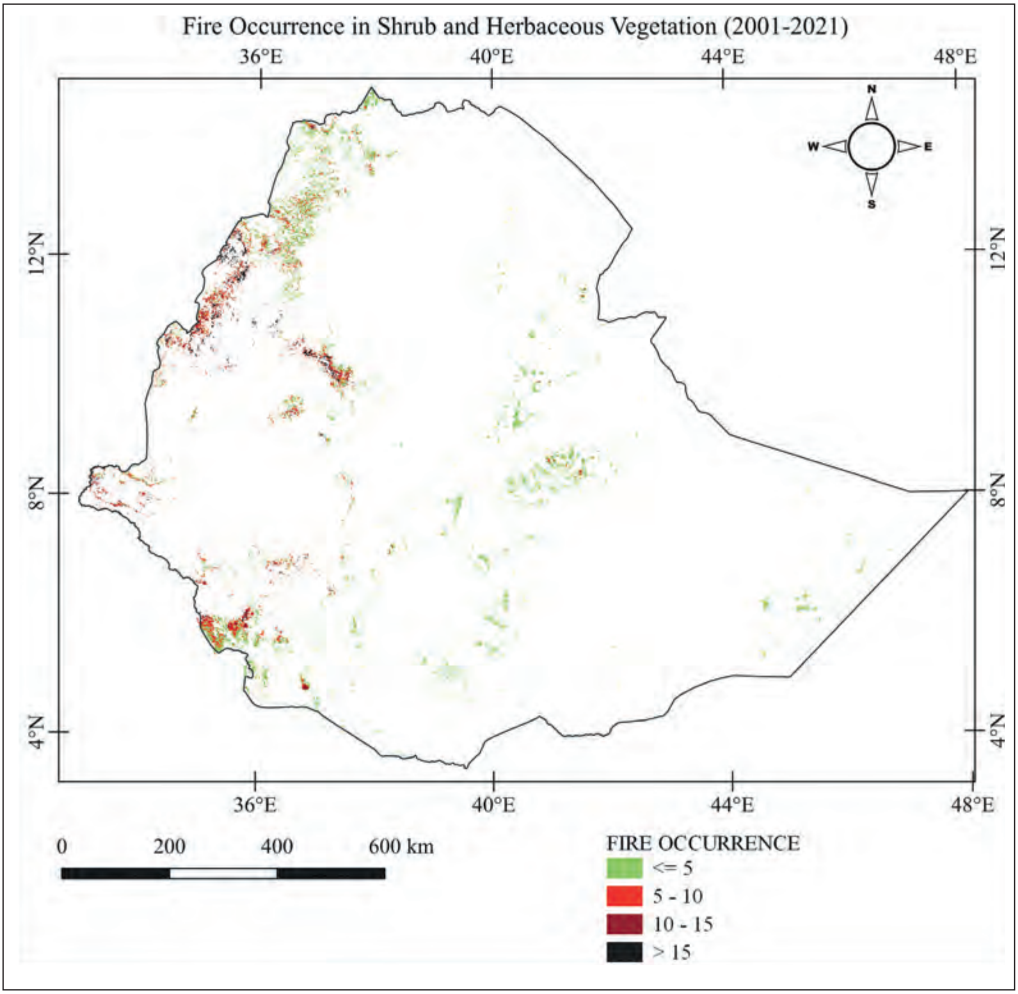
Spatial distribution of fire occurrence in forest lands: As the figure below shows the spatial distribution of the burn-affected areas in forest-dominated areas in Ethiopia based on the data from 2001 to 2021.

Figure 7: National level spatial distribution of fire occurrence in forest dominated areas



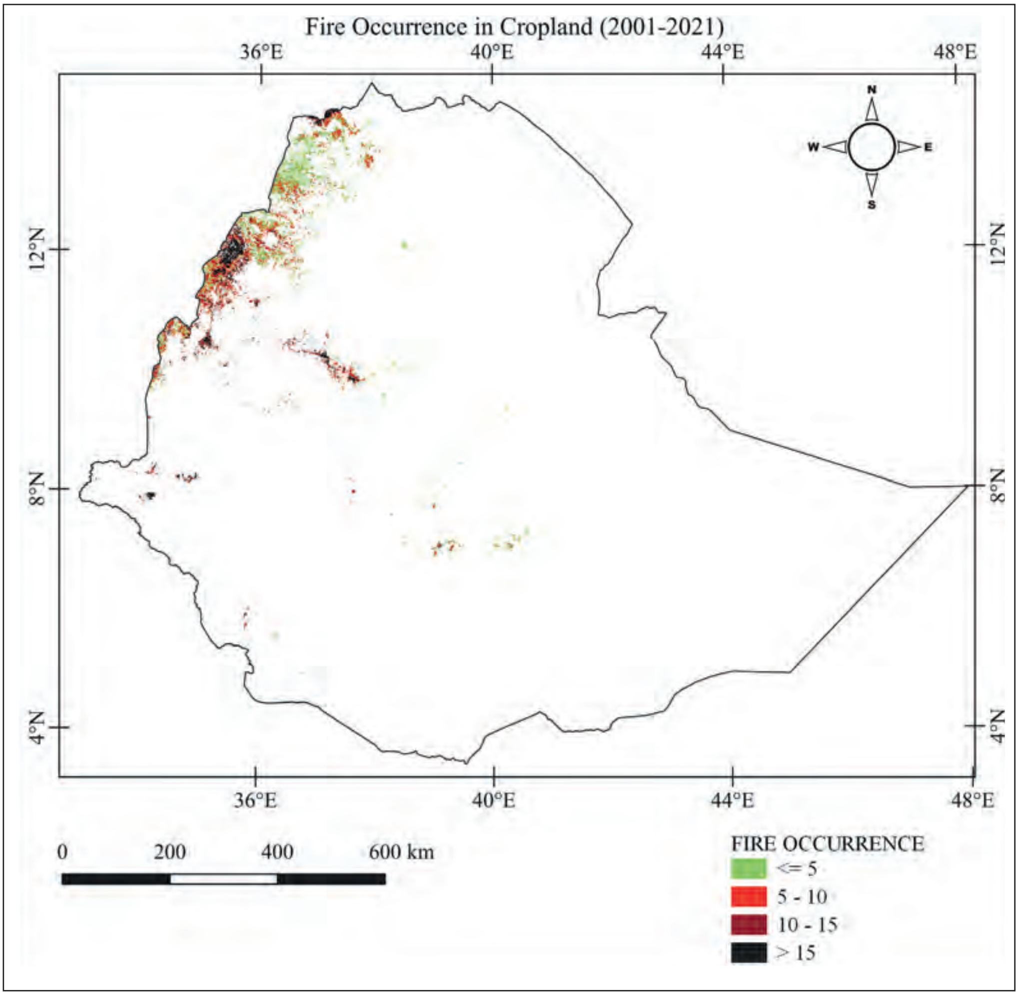
Spatial distribution of burned area in shrub/herbaceous land: Figure 8 shows the spatial distribution of the burn-affected areas in shrub and herbaceous vegetation-dominated areas in Ethiopia based on the data from 2001 to 2021.

Figure 8: National level spatial distribution of fire occurrence in shrub / herbaceous vegetation dominated areas



Spatial distribution of fire occurrence in crop lands: Figure 9 illustrates the spatial distribution of the burn-affected cropland for Ethiopia based on the data from 2001 to 2021.

Figure 9: Spatial distribution of fire occurrence in crop lands in Ethiopia



2.3.3. Wildfire hotspot areas

The fire hotspot areas are located in North-West, West, and South-West Ethiopia. The figure shows the location of the fire hotspots in Ethiopia based on observations from 2002 to 2021.

Figure 10: Fire host spot area across Ethiopia: class 1 (10-15 years of fire occurrence), class 2 (over 15 years of fire occurrence)

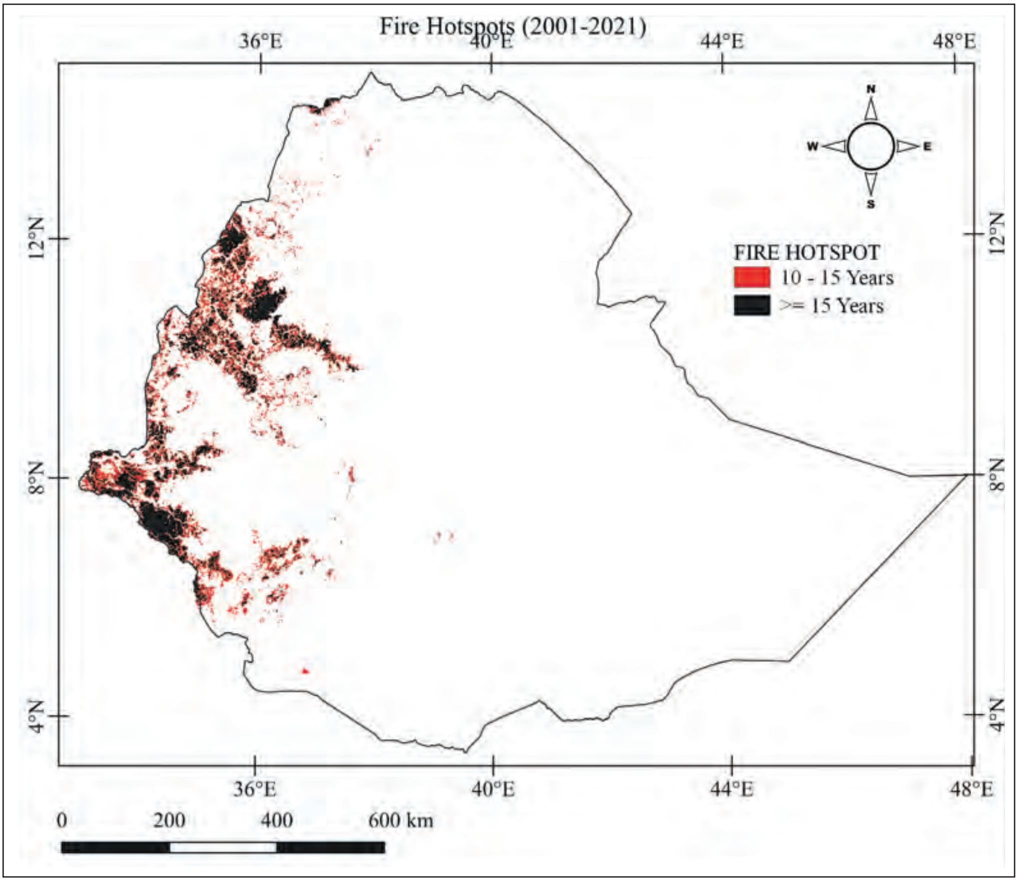


Figure 11: Fire hot spot areas and districts in Ethiopia: class 1 (10-15 years of fire occurrence), class 2 (over 15 years of fire occurrence) and the district administrations

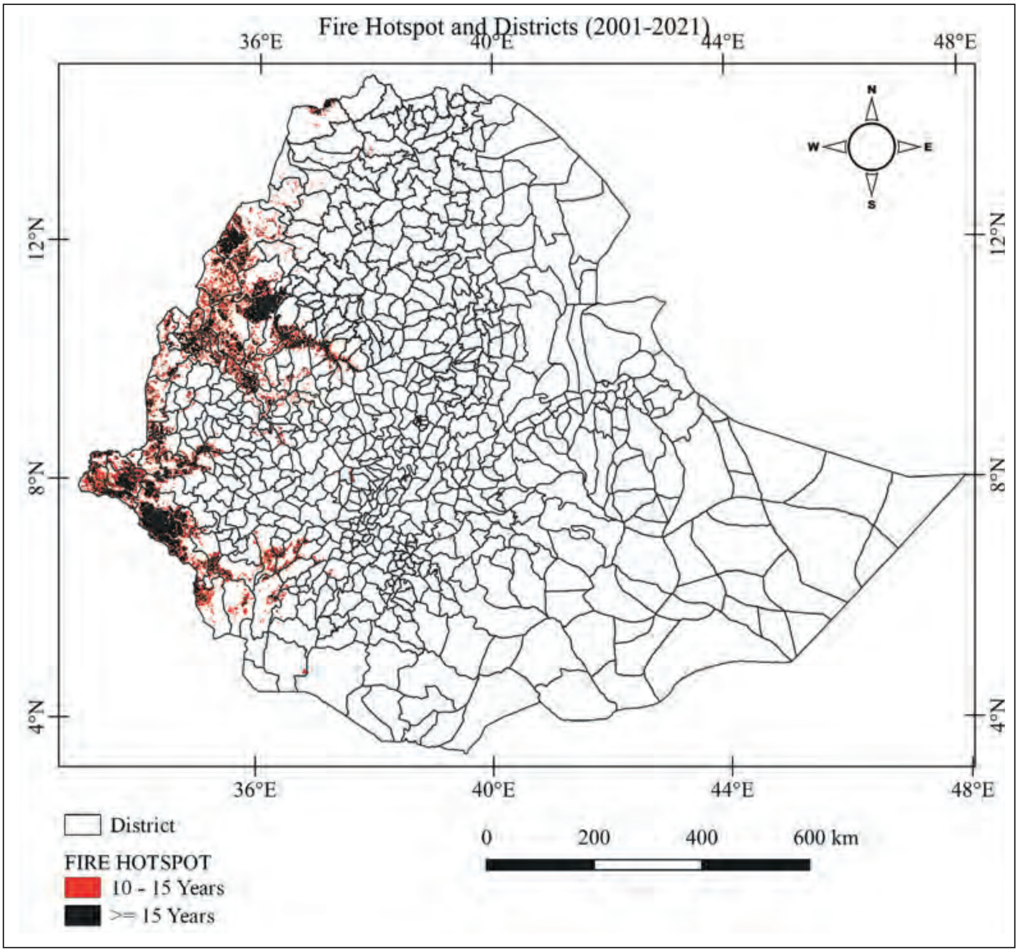
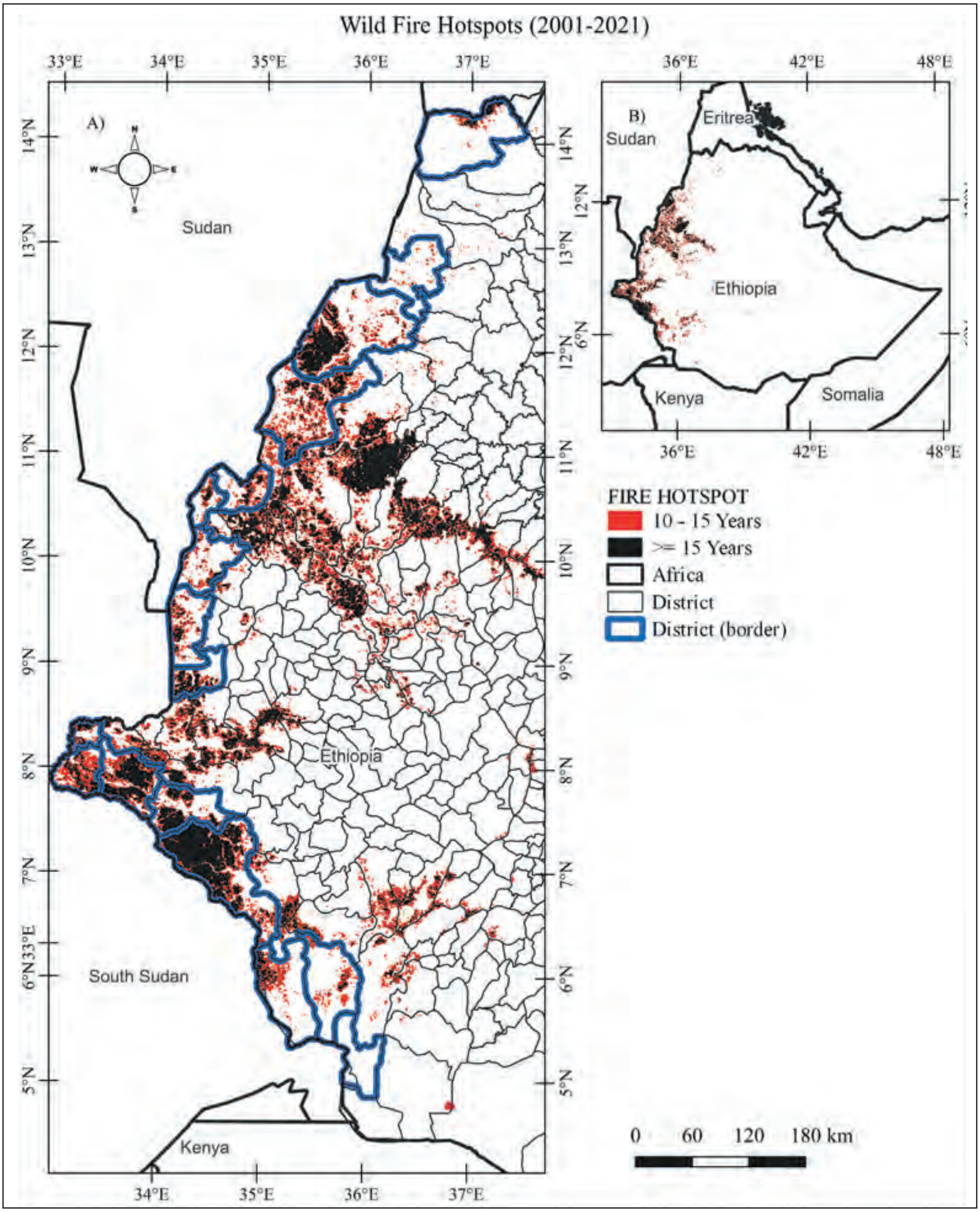


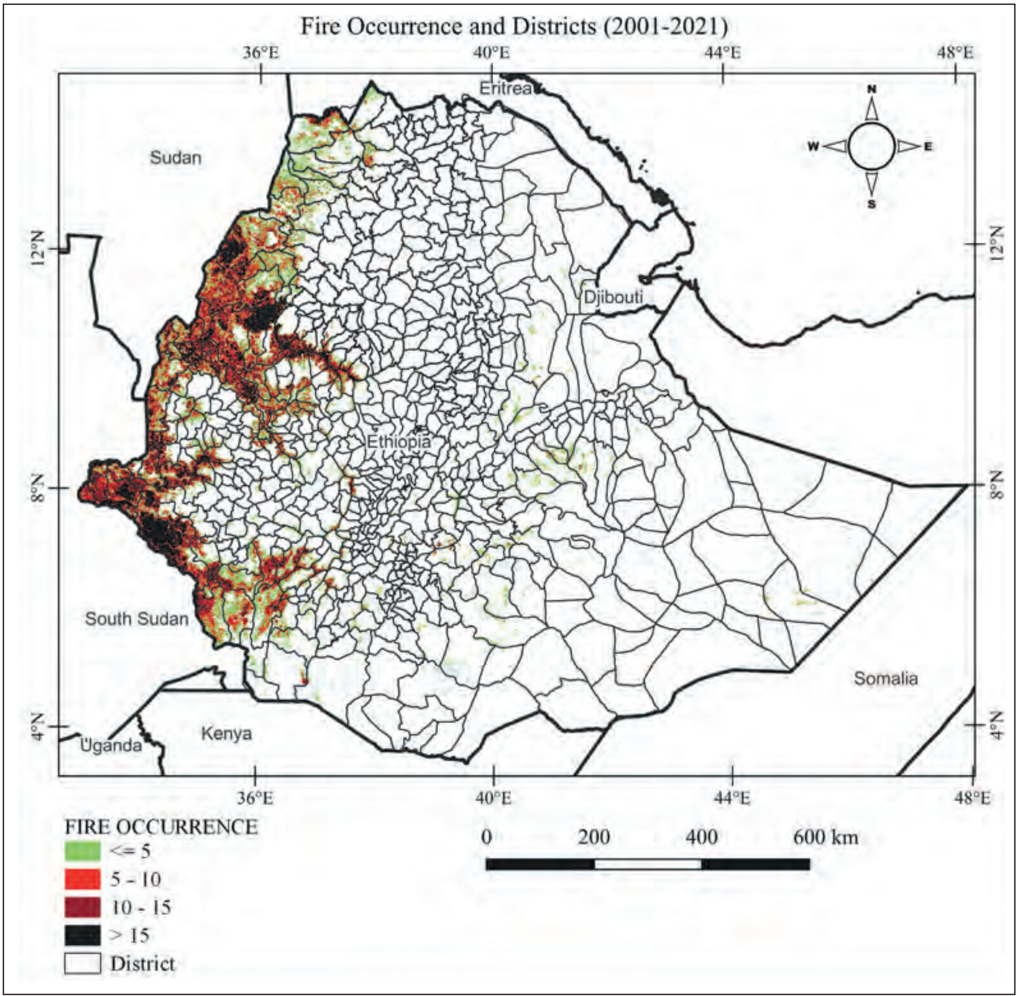
Figure 12: Fire hotspots in districts bordering neighbouring countries of Ethiopia: blue lines represent the districts with large areas of fire hotspots. The map on the left side shows the districts neighbouring Sudan and South Sudan while the one in the right shows Ethiopian level.



2.3.4 Districts with frequent wildfires

The spatial distribution of fire occurrences varies from district to district. Most of districts with more fire occurrences are found in western and southwestern Ethiopia. The figure below shows the spatial distribution of burned area occurrence in relation to fire prone districts of Ethiopia. It shows that fire occurs independent of the land cover types.

Figure 13: Spatial distribution of fire occurrence in Ethiopia by districts independent of the land cover types



Figures 14, 15 and 16 show the spatial distribution of fire occurrences in selected districts. The study has produced such maps for all districts. Thus, which areas in fire prone districts are more vulnerable have also been mapped to facilitate selection of specific intervention areas and plan interventions.

Figure 14: Spatial distribution of fire occurrence in Assosa district

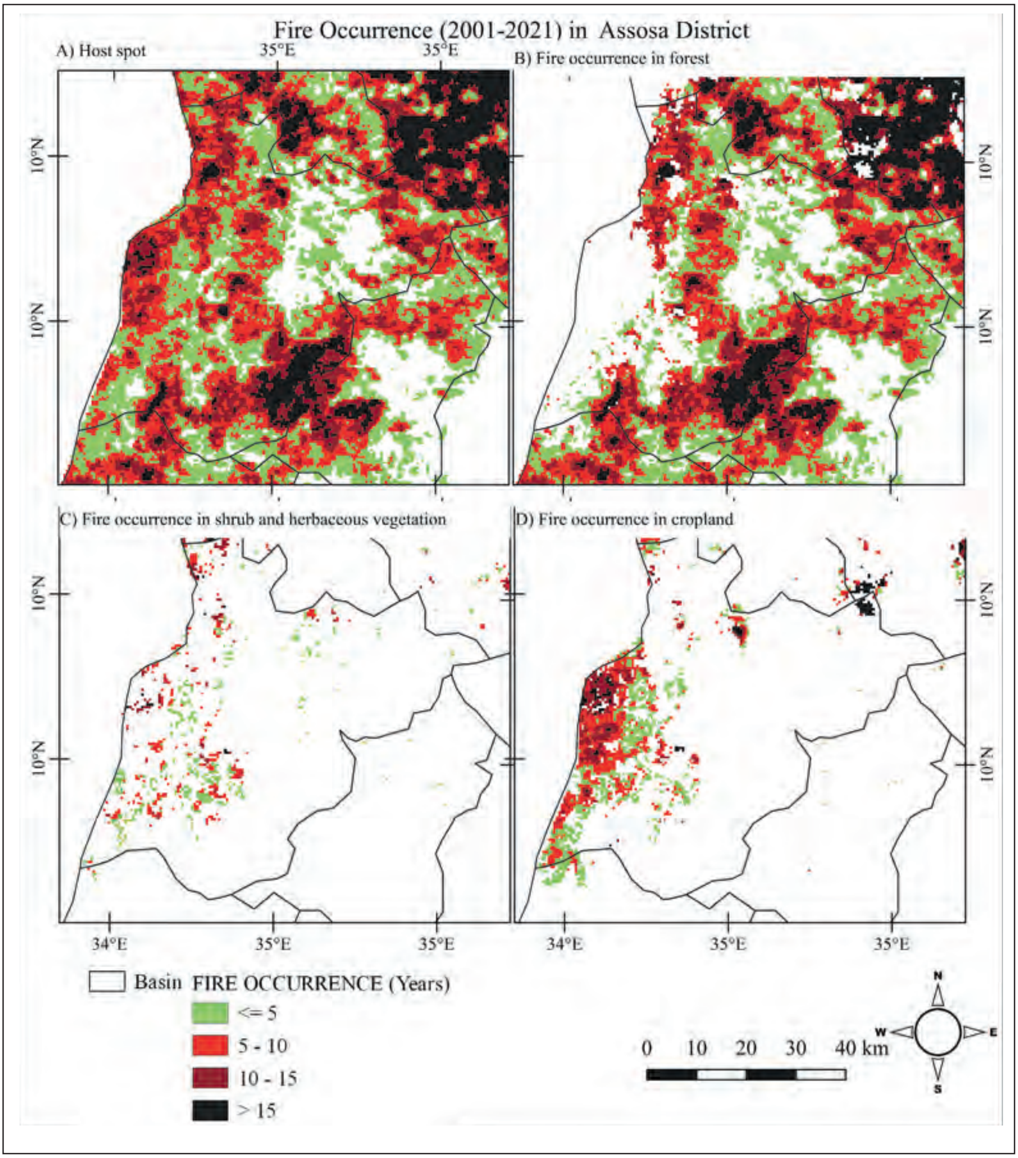


Figure 15: Spatial distribution of fire occurrence in Dodola district

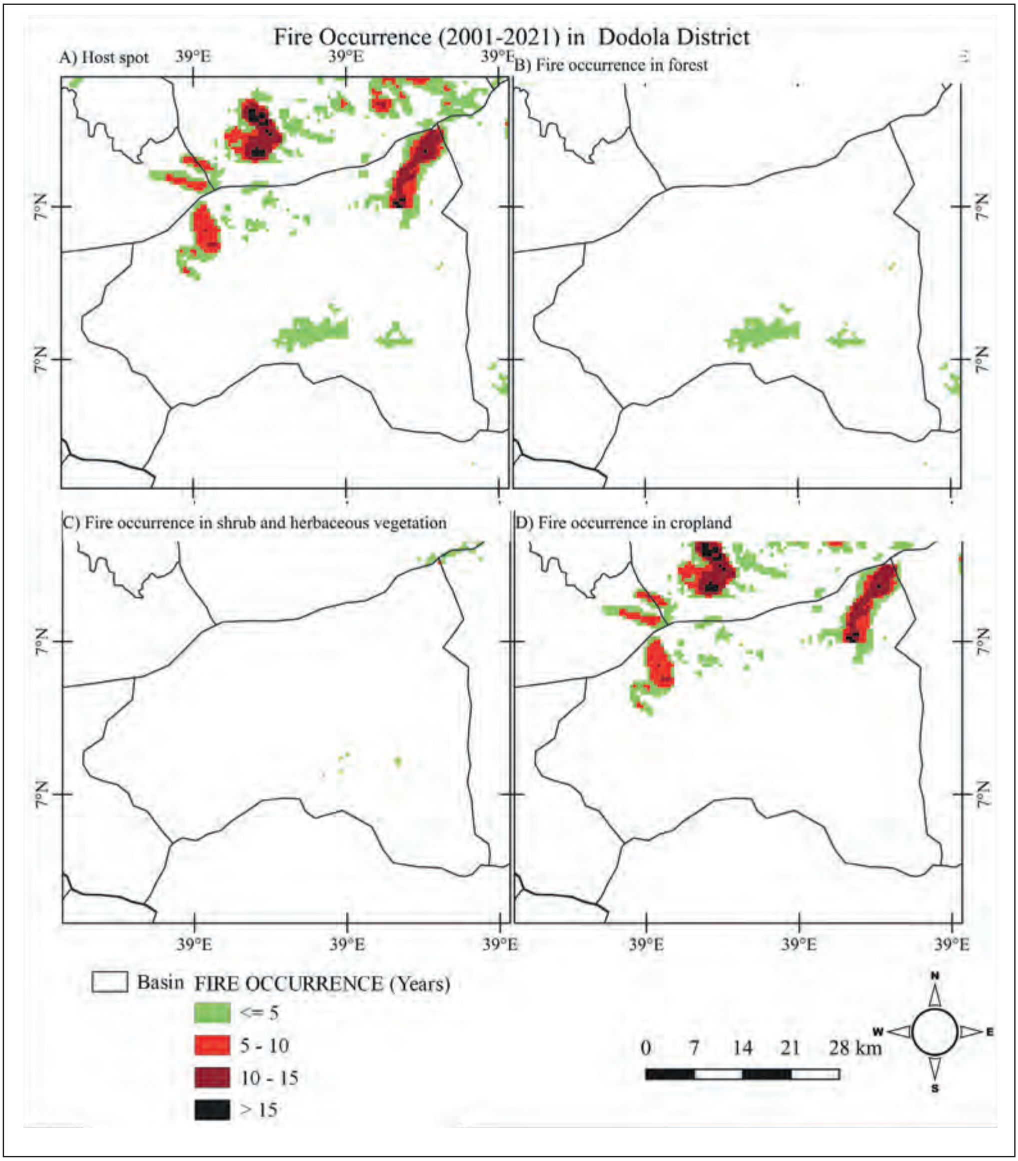


Figure 16: Spatial distribution of fire occurrence Enemorina Ener district

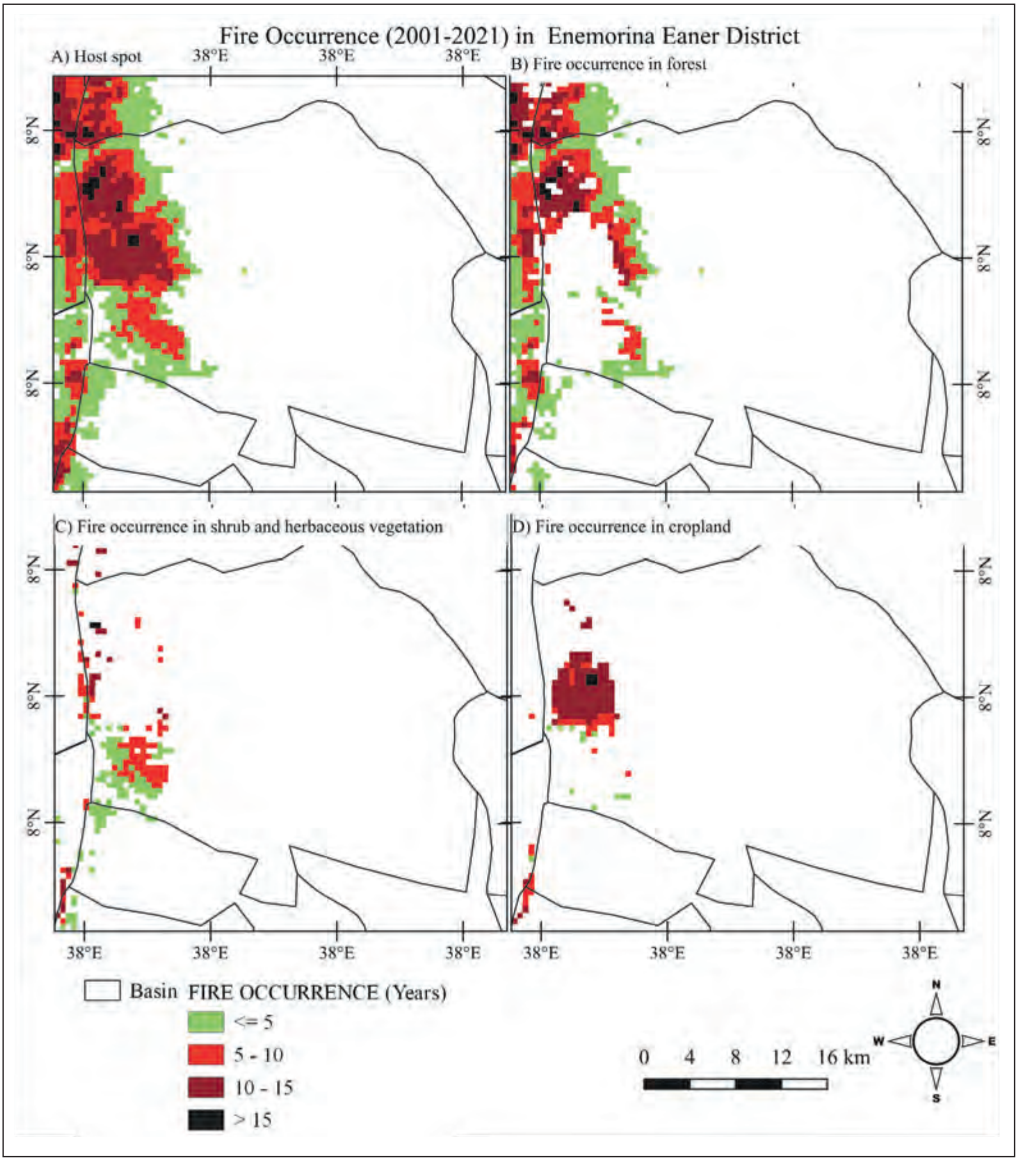


Table 9: Burned area in ha by region, zone, district, and land cover between 2002 and 2021.

Region	Zone	District	Land cover	Area in (1000 hectare) by Year						
				02	03	04	05	06	07	08
Amhara	North Gonder	Quara	Forest	1	2	3	6	5	4	3
			Shrub	103	143	141	169	172	157	158
Benishangul Gumuz	Assosa	Menge	Forest	77	90	88	98	95	96	90
			Shrub	7	11	15	14	13	13	12
	Kemashi	Sirba Abay	Forest	43	65	68	75	89	88	63
			Shrub	18	38	36	40	36	43	38
		Yaso	Forest	94	119	109	116	125	121	94
			Shrub	0	1	1	0	1	1	1
	Metekel	Bulen	Forest	98	179	170	178	171	170	160
			Shrub	2	5	5	5	4	4	4
		Dangura	Forest	161	210	183	223	216	204	188
			Shrub	2	5	6	8	10	11	10
		Guba	Forest	51	90	88	116	143	95	117
			Shrub	45	90	94	118	146	107	132
		Wenbera	Forest	261	326	286	312	342	339	306
			Shrub	11	15	14	10	10	10	8
Gambela	Agnuak	Dima	Forest	470	539	492	540	545	473	506
			Shrub	7	8	9	10	14	12	11
		Gambela Zuria	Forest	99	130	101	138	128	120	129
			Shrub	1	2	2	4	4	3	4
		Goge	Forest	110	160	141	147	158	148	163
			Shrub	2	3	3	3	5	1	4
		Jore	Forest	207	233	217	165	178	147	213
			Shrub	9	17	17	16	18	12	24
	Nuer	Akobo	Forest	149	126	109	72	84	99	85
			Shrub	11	10	12	6	8	10	16
SNNPR	Bench Maji	Surma	Forest	123	101	73	115	122	27	91
			Shrub	77	31	25	21	49	25	51

2.2.5 Fire incidence trend in fire prone districts

Time series data on burned areas by administration and land cover: The fire incidence trend shows variations from district to district. There has been intra- and inter-annual fire incidence variation within the same district. A fire may occur on a time scale of less than one year but

09	10	11	12	13	14	15	16	17	18	19	20	21
4	3	2	2	3	2	4	3	3	3	3	3	1
177	173	153	180	175	148	146	133	165	159	181	210	237
79	81	82	87	80	83	85	92	85	86	89	82	65
15	17	17	14	11	9	9	8	7	5	3	3	2
80	62	66	71	65	72	77	82	70	62	68	56	53
54	66	66	45	36	34	30	30	25	20	24	13	16
93	122	105	119	101	98	90	88	95	95	123	99	101
1	1	1	1	1	1	1	1	1	1	3	3	3
151	156	148	166	147	140	129	128	130	132	133	126	121
4	6	6	5	4	2	1	2	2	3	1	2	1
183	189	177	189	157	134	140	139	129	111	119	125	128
19	27	30	27	22	17	14	18	12	7	7	27	14
107	105	93	108	87	92	92	92	117	97	97	76	103
149	174	164	139	121	123	91	99	122	91	114	87	95
349	338	315	369	309	296	295	331	305	296	316	291	271
14	25	26	20	13	8	6	4	4	3	3	3	2
485	566	505	525	429	460	477	486	515	496	472	258	391
11	9	13	12	8	10	12	9	10	14	9	2	3
116	151	113	125	107	137	120	122	125	99	110	91	91
4	5	3	2	2	3	2	3	4	2	3	2	3
143	155	129	153	150	152	148	149	144	137	143	116	113
4	2	5	4	4	1	3	5	6	3	6	2	2
182	199	201	209	192	161	168	196	218	150	212	66	175
19	31	29	31	31	23	32	22	48	33	35	10	40
97	65	98	112	81	86	102	120	127	114	147	37	86
18	16	25	18	29	21	23	16	26	11	13	6	4
69	51	67	123	77	108	129	92	101	105	101	20	75
27	15	21	91	71	58	71	65	25	37	21	23	20

more than one month in some cases. The focus of this analysis instead addressed the inter-annual variations by district. The table above shows the burned area-related information of selected districts (as examples). The figures below shows the trend of the approximated burned area of selected sample districts by year, land cover, and district.

Annual burned area comparison by land cover: The figures below provides summary of burned area in the selected districts and the trend overtime by land cover.

Figure 17. Burned area by year and land cover for Akobo district

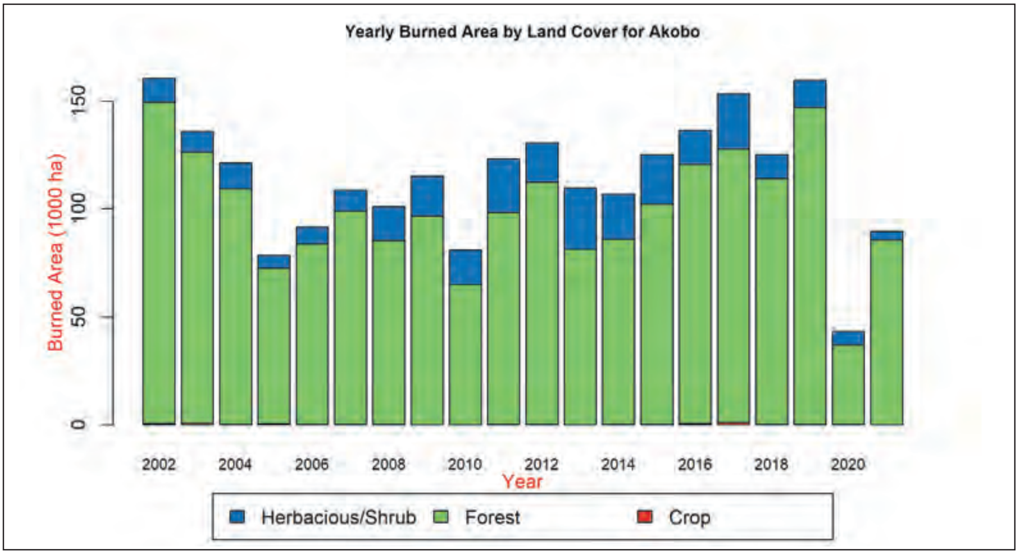


Figure 18: Burned area by year and land cover for Gambella Zuira district

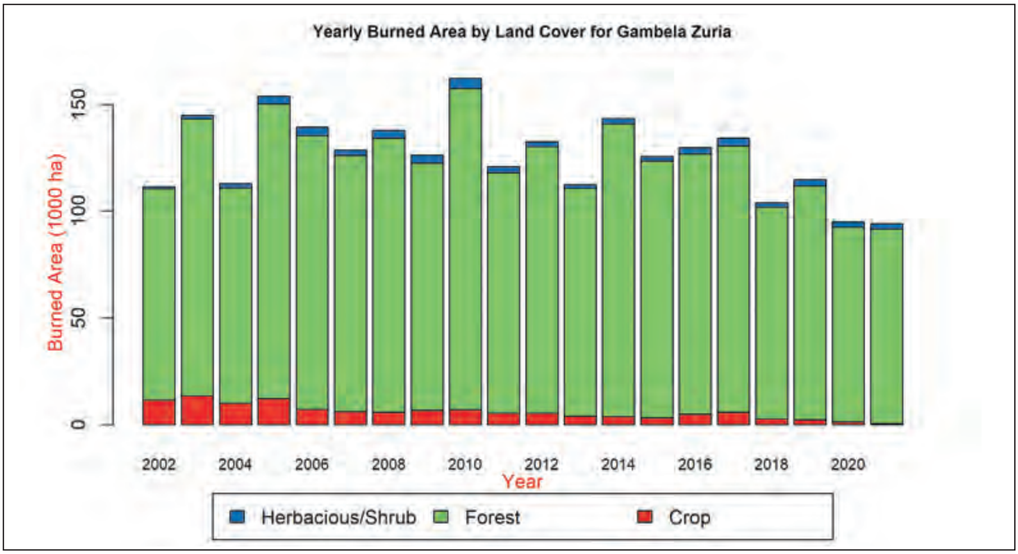


Figure 19: Burned area by year and land cover for Guba district, Benishagul Gumuz Region

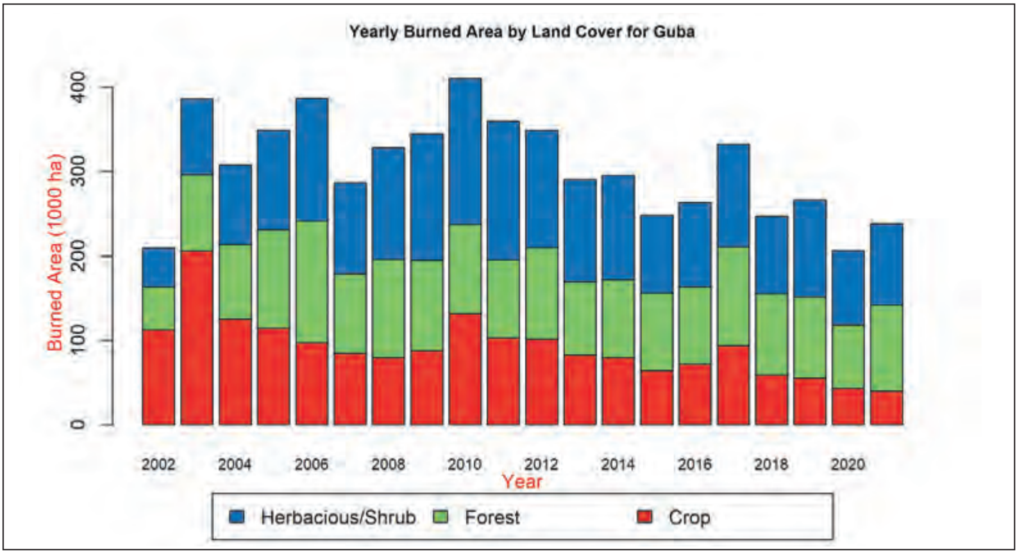
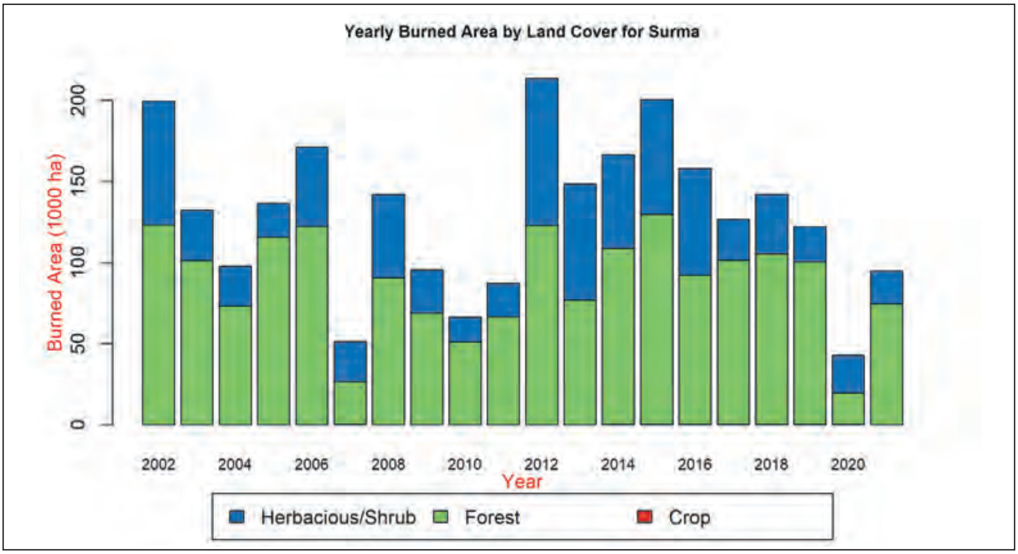


Figure 20: Burned area by year and land cover for Suram district, Southwester Ethiopia Peoples' Region



Monthly burned area comparison by land cover: The intra-annual burned area information was generated at district level. The information includes the area affected by fire by land cover, and month. The supplementary table generated by this study and attached as Annex provides the monthly trend data for all fire affected districts.

Table 10: Burned area in ha by district, land cover and month

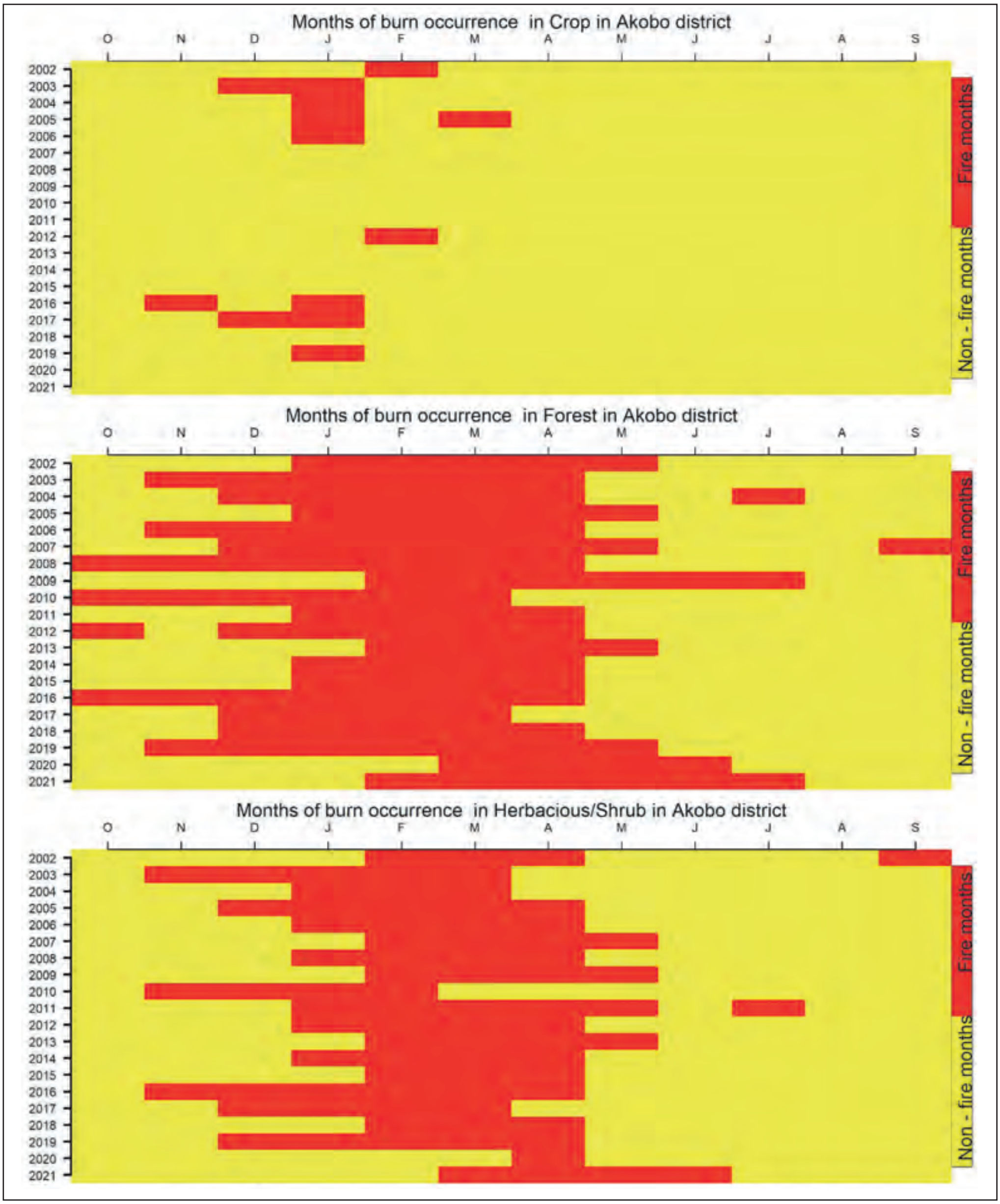
Region	Zone	District	Land cover	Month			
				O	N	D	J
Amhara	North Gonder	Quara	Forest	0	299	1274	526
			Shrub	2461	36762	20706	6663
Benishangul Gumuz	Assosa	Menge	Forest	88	2376	5071	19154
			Shrub	6	107	204	855
	Kemashi	Sirba Abay	Forest	593	7454	12741	13610
			Shrub	309	4620	3844	1773
		Yaso	Forest	170	3078	16473	33908
			Shrub	19	54	101	226
	Metekel	Bulen	Forest	106	1663	8908	29511
			Shrub	1	9	13	132
		Dangura	Forest	1176	10630	18980	49675
			Shrub	44	70	373	1443
		Guba	Forest	413	21785	44356	19091
			Shrub	1315	23238	20369	4992
		Wenbera	Forest	860	31885	74780	53849
			Shrub	27	373	355	388
Gambela	Agnuak	Dima	Forest	3270	15639	96643	240261
			Shrub	164	472	1074	1434
		Gambela Zuria	Forest	4080	21 915	54238	28785
			Shrub	166	554	368	150
		Goge	Forest	124	7353	55035	58661
			Shrub	1	36	246	340
		Jore	Forest	12 6	1560	18176	31666
			Shrub	1	39	219	1525
	Nuer	Akobo	Forest	135	1413	9719	22330
			Shrub	1	83	389	1258
SNNPR	Bench Maji	Surma	Forest	2241	4425	12026	23740
			Shrub	799	1518	3037	5608

Seasonality of burn trends: Fire is mainly used to clear land for cultivation, and the timing is synchronized with the dry season before the onset of rains. Fire is used at least once a year so that the land is ready for ploughing at the beginning of the planting season. Fire is used in the lowland areas, where livestock raising is an important part of the economy, to control tsetse fly or ticks, or to induce sprouting of fresh grass or

F	M	A	M	J	J	A	S
156	444	254	33	0	0	0	0
4305	4756	4233	2135	11	0	0	1
27610	25213	5571	398	0	0	0	0
1361	1496	1022	90	0	0	0	0
13856	12226	8138	53	0	0	0	1
1793	1988	3219	99	0	0	0	1
36460	12941	2205	0	0	0	0	0
202	25	23	1	0	0	0	0
40486	57450	8286	70	0	0	0	0
399	812	2 8 5	1	0	0	0	0
47880	24525	11946	340	0	0	0	0
1903	1949	1273	221	0	0	0	0
6233	4283	2141	24	0	0	0	0
2319	2835	2298	165	0	0	0	1 8
41885	56875	51355	1203	0	0	0	0
452	1351	2224	38	0	0	0	0
100824	19145	795	31	73	290	1500	3030
1184	335	14	0	0	6	75	118
7058	1218	159	0	0	5	8	161
41	54	12	0	0	0	0	5
16805	3874	944	3	24	101	11	55
394	493	189	1	1	3	4	0
61763	52969	15100	1096	1645	15	29	330
4914	3918	1684	82	23	1	2	0
33130	19093	12574	895	379	88	4	16
1960	1634	1961	94	18	3	1	5
32326	9279	606	363	224	310	601	2360
4828	2223	286	246	166	115	339	1409

browses. Fire is also used to smoke bees during harvesting honey. All these activities have temporal aspects. In Ethiopia, the accumulation of fuel load and flammability attain peak values in a certain period of the year. The timing of forest fires and the extent of effects depend on the type of economic activity of the area and the type of forest formation.

Figure 21. Fire- and non- fire months by year for Akobo district using the 2002 to 2021 data



Annual and monthly occurrence of burn by district: The burn occurrence varies not only by site but also by time of occurrence within a year. Figures 21-25 demonstrate variations in the fire-months. The red and yellow colour indicate fire during and outside fire months.

Figure 22. Fire- and non- fire months by year for Gambella Zuria district

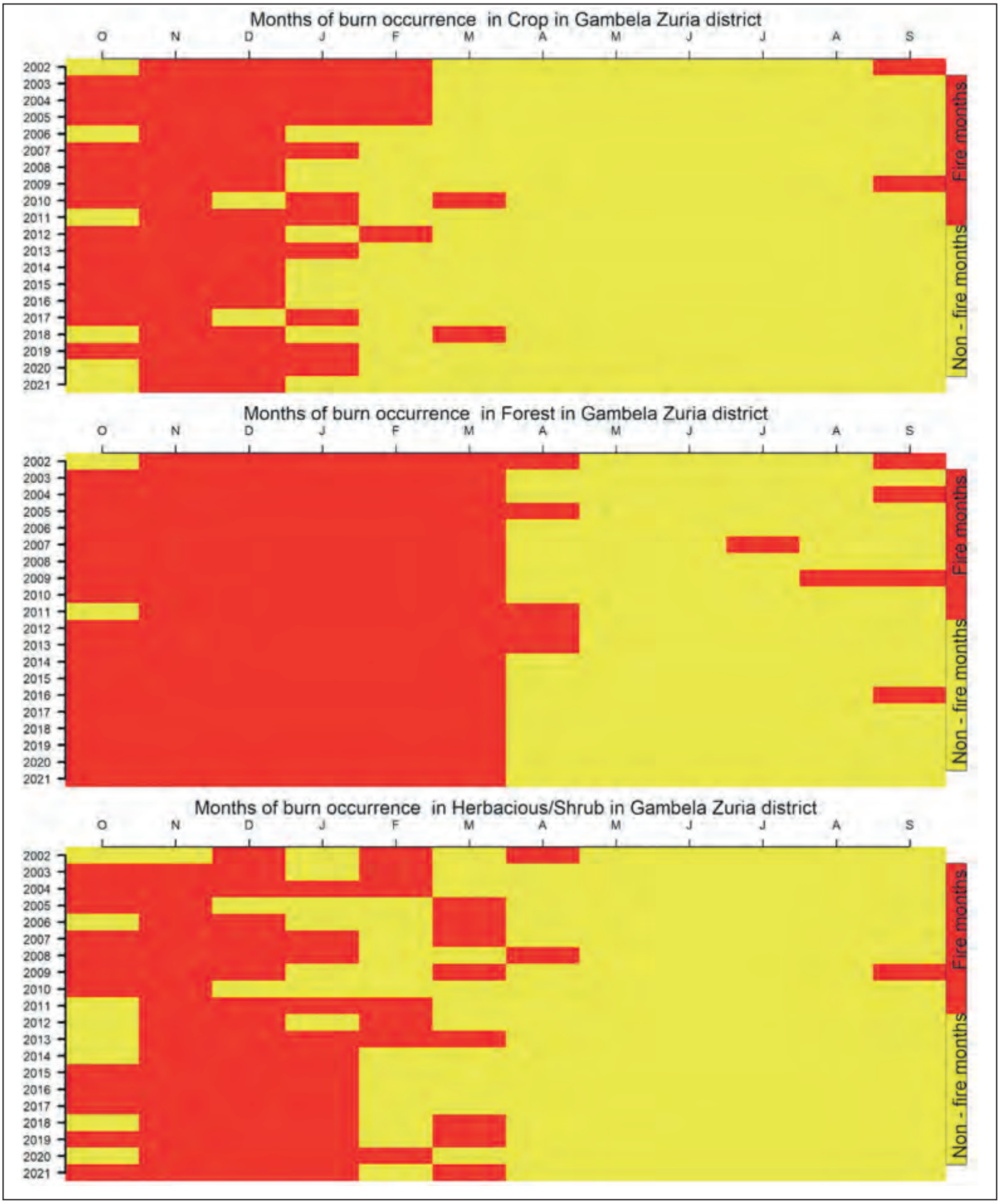


Figure 23: Fire- and non- fire months by year for Guba district

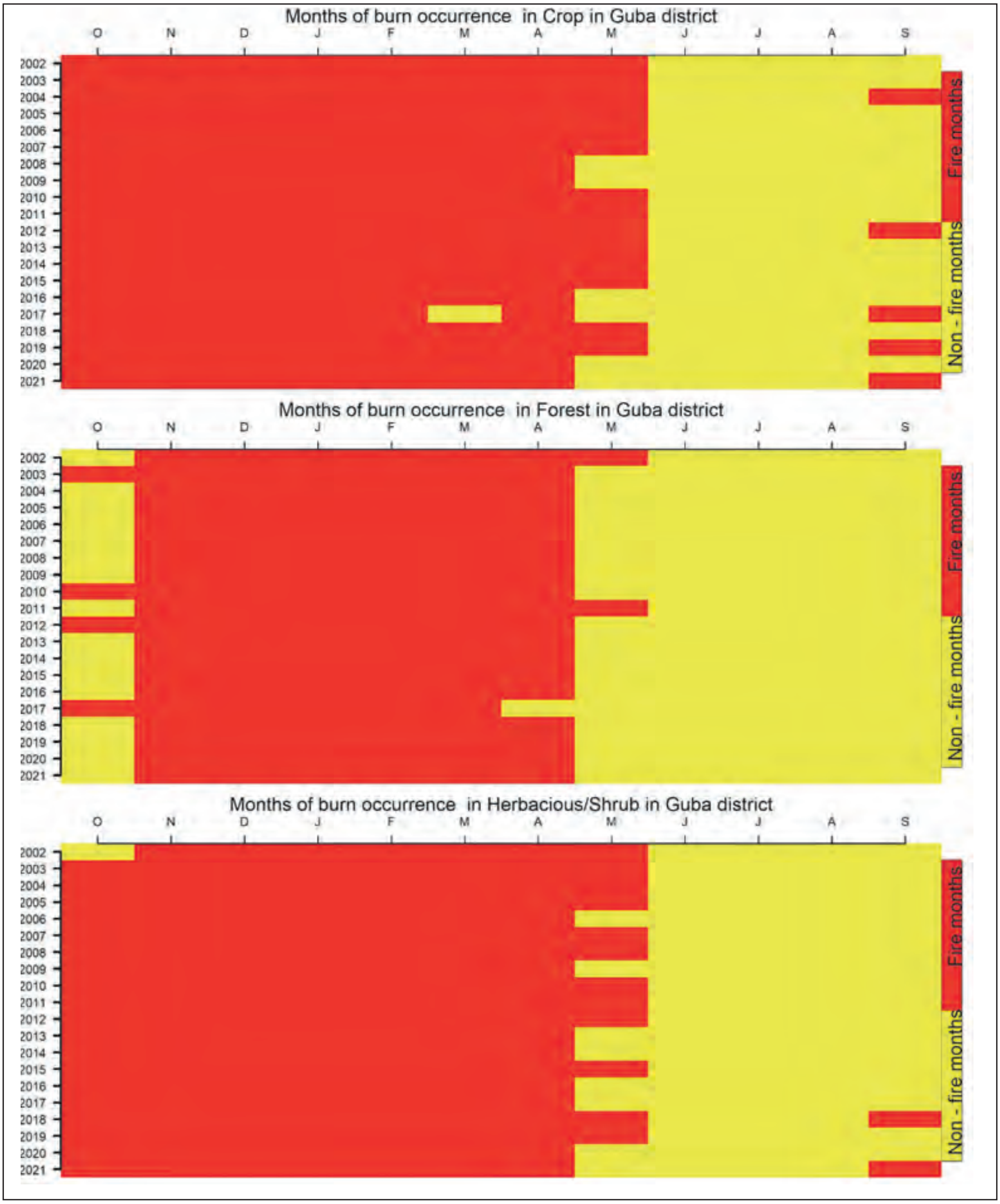


Figure 24: Fire- and non-fire months by year for Quara district

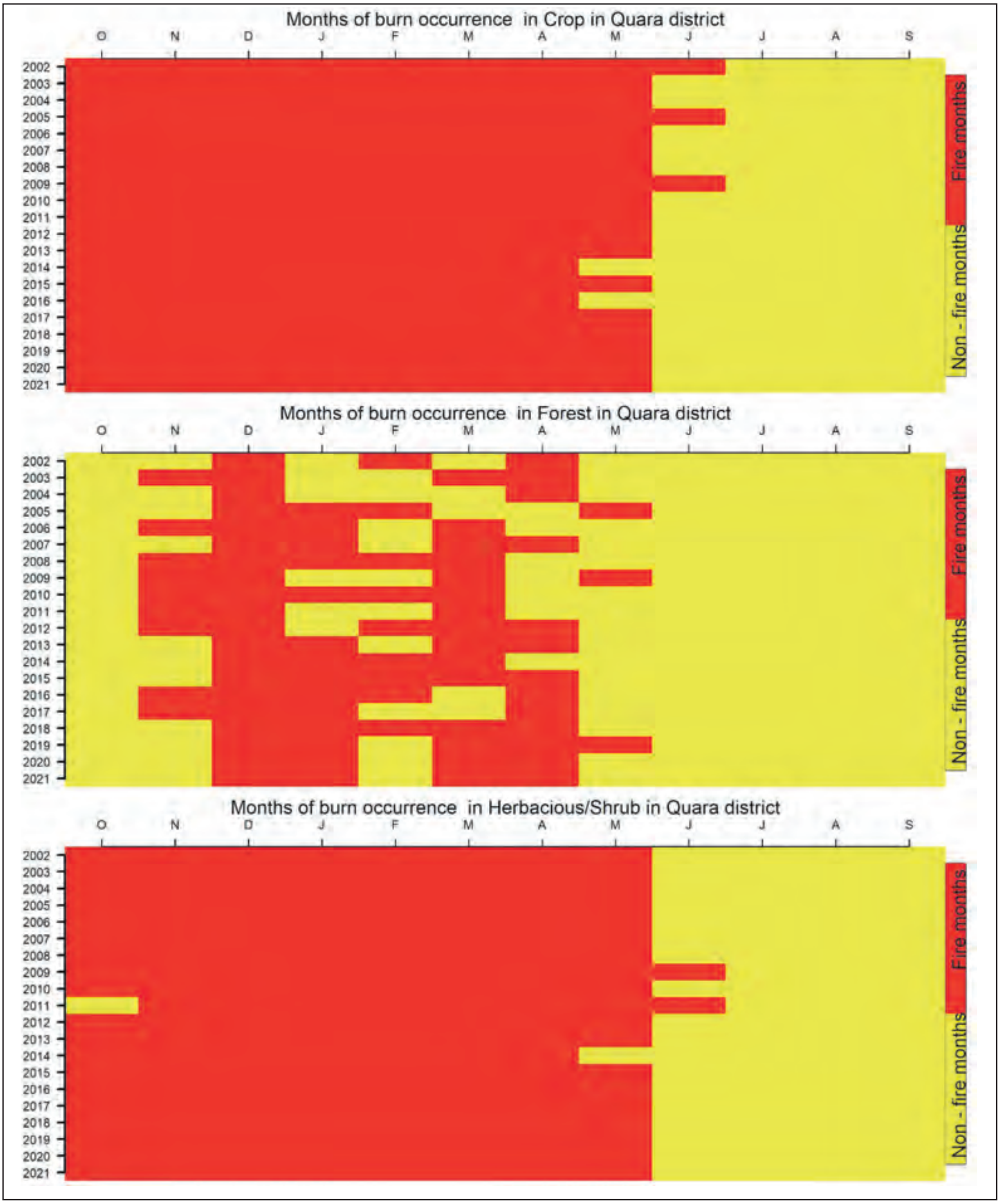
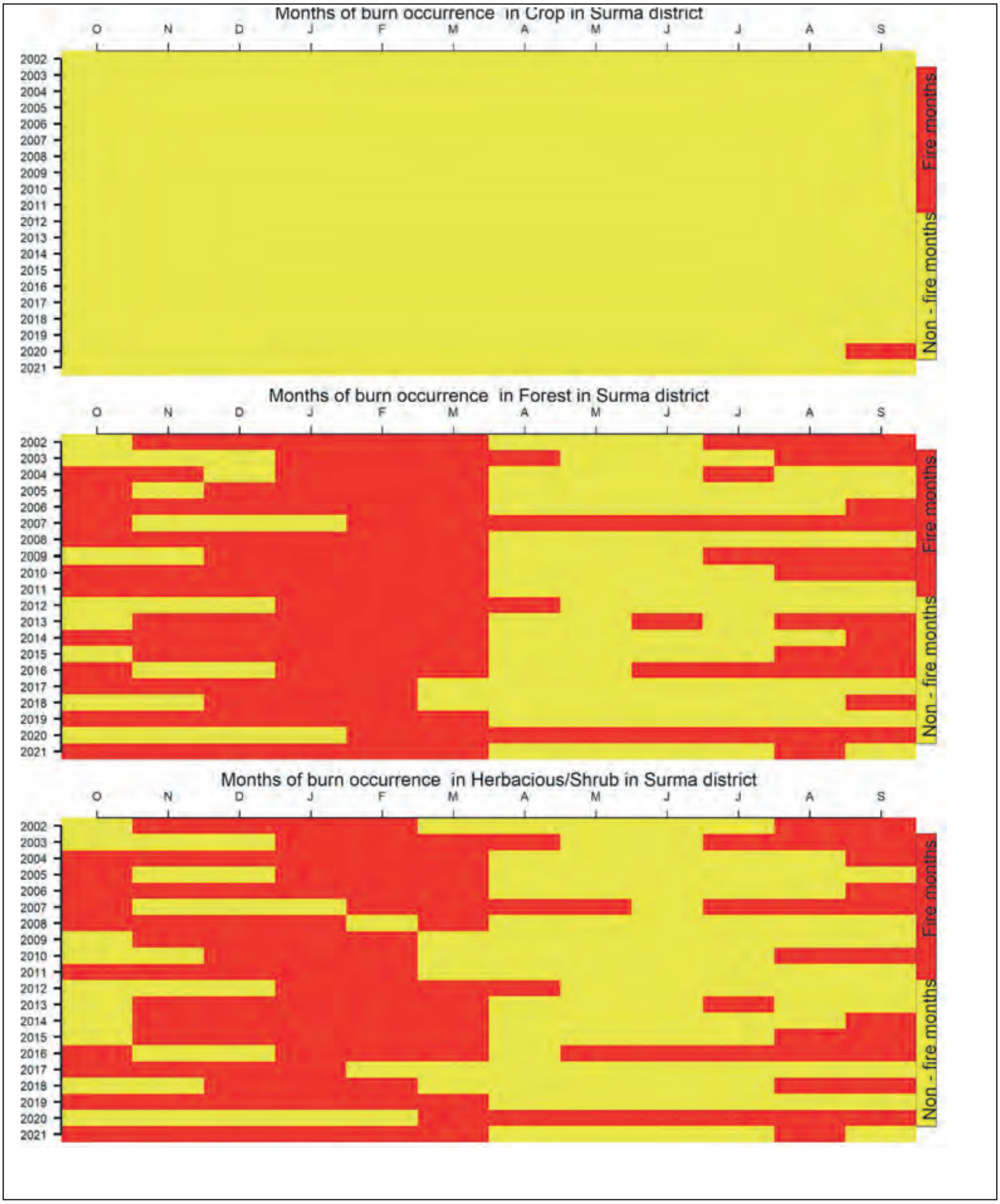


Figure 25. Fire- and non- fire months by year for Sumra district



Chapter 3: Review of trends of wildfire and fire management practices

3.1. Trend and recent occurrences of wildfires in Ethiopia

Ethiopia's forest resources have dwindled over the years largely due to various anthropogenic pressures which directly or indirectly contribute to forest degradation and the conversion of forests to other land uses (Teketay, 2000). Ethiopia's REDD+ Strategy identified agricultural expansion and unsustainable biomass extraction for household energy as major drivers of deforestation and forest degradation (MEFCC, 2018a). The strategy further noted that underlying causes are absence of land use policy and plan, weak law enforcement, population pressure and rural poverty (MEFCC, 2018a). The relative importance of different drivers of forest loss may vary across forest biomes depending on local socioeconomic, demographic and biophysical contexts (MEFCC, 2018b). The report ranked forest fires as having high impact in Benishangul Gumuz and Gambella, and medium impacts in Amhara, SNNP, Tigray and Oromia regional states (MEFCC, 2018a).

Ethiopia's diverse agroecological zones, physiogeographic diversity, and macro and microclimatic variability result in heterogeneous landscapes with variable (uni/bimodal) precipitation and temperature regimes (Anonymous, 1988) that impact occurrence and impacts of fire. According to Archibald et al. (2013), attributes that account for most spatial variation in burned areas in Africa are environmental, mainly rainfall, temperature, soil nutrients and topography. In the past few decades, the spatial occurrence of wildfires has expanded to cover more forest biomes in several regional states and has become a growing concern in Ethiopia. However, apart from observational reports (See Table 12 on page 52), information on the occurrence of wildfires and their impacts in Ethiopia is scanty. This remains to be a major gap in putting in place effective forest fire management system.

According to van Bruegel et al. (2016), there is a clear congruence between distribution patterns of fire and major vegetation types in Ethiopia. Historically, an annual cycle of natural fire incidences was seen in lowland vegetation, particularly bush land and grassland formations (Bekele and Mengesha, 2001). For example, *Combretum-Terminalia* woodlands in north-western, western and south-western Ethiopia undergo an annual fire cycle in the dry season and woody species are well-adapted to this cyclical fire (Teketay, 2000). The importance of climate as principal driver of natural wildfires is significant, particularly in areas with high fire frequencies and median to high annual rainfall, coupled with a long dry season with high mean temperatures (Meyn et al., 2007). Such conditions are predominantly found in the western lowlands where *Combretum–Terminalia* woodland and wooded grasslands (CTW), and wooded grasslands of the western Gambella region (WGG) are the major forms of natural vegetation.

The boundaries between the CTW and moist and dry Afromontane forests also coincide with a sharp decrease in fires. A possible explanation is the relative high moisture content of fuels in the dry Afromontane forests (DAF), making spontaneous combustion and spread of fires

Table 12: Reports of forest fires (1984-2022)

Year	Forest area (ha)	Most affected areas	Source
1984	308,198	High forests	Teketay 2000; George and Mutch 2001, in Lemessa & Perault, 2001
1985-1989	-	-	No data
1990	1,072	-	Bekele and Mengesha, 2001, Anonymous 2022
1991	153	-	Bekele and Mengesha, 2001
1992	32	-	Bekele and Mengesha, 2001
1993	3,159	-	Bekele and Mengesha, 2001; Anonymous, 2022
1994	1,550	-	Bekele and Mengesha, 2001; Anonymous, 2022
1995-1998	-	-	No data
1999-2001	158,866	Bale mountains forests, woodlands, grasslands	MoA (2002) in Getahun (2009)
2002-2007	-	-	No data
2008	12,825	Bale mountains, Bale zone (forest, bamboo, ericaceous belt). Asebot forests	Temesgen and Gebru (2015)
	12,700		Worku and Zewdie (2008)
2009	700,000		MOA (2009) cited in Getahun (2009)
2010-2012	-	-	No data
2013		Yayu Biosphere Reserve	Anonymous 2022
2014-2018			No data
2019	7,000	Simien National Park	Anonymous 2022
2020	-	-	"Widespread fires in 2020" was mentioned in reports
2021	28,497	Wof Washa; Simen National Park	EFCCC 2022 Unpublished in Anonymous, 2022
2022	10,443		Global Disaster Alert and Cooperation System (GDACS), Anonymous 2022

less likely (Ericksson et al., 2003). The high fuel moisture content cannot be explained by rainfall alone, as rainfall frequency distribution in the MAF and DAF largely overlaps with that in the CTW. Other factors that are likely to contribute to high fuel moisture content in the highlands are relative low temperatures in the dry season and shorter dry seasons compared to those in the CTW (Friis et al., 2010).

Based on an experimental fire study in *Acacia* woodlands and dry Afromontane forests in southern Ethiopia, it was found that frequent fires had only limited or no historical role in the development of dry Afromontane forests, and the introduction of fire could profoundly

Table 13: Forest fire incidence, its drivers and level of sensitivity of different vegetation types (Adapted and modified from MoA, 2000)

Biome	Vegetation categories	Incidence	Driver		Sensitivity (potential to recover)
			Direct cause	*Population density*	
Acacia-Commi phora (AC)	Desert and Semi-desert Scrubland	Infrequent/ rare	Wildfires	Moderate	Sensitive
	Acacia-Commiphora, small leaved deciduous woodland	Cyclical	Agriculture/grazing, charcoal, ticks, honey, control of bush, hunting	Low	Low sensitivity
Dry Afro-montane forest (DAF)	Afroalpine	Rare	Wildfire	Low	Extremely sensitive
	Sub-Afroalpine	Infrequent/ Cyclical	Access, grazing, hunting, fend off wild animals	Low	Non-sensitive adapted to fire
	Dry evergreen montane forest	Annual-irregular/burned annually for slash and burn	Clearing for agriculture, wild honey extraction	Very high	Sensitive
	Montane grasslands	No fires	Agriculture, Tick control	Moderately High	Extremely Sensitive
	Montane evergreen thickets	Annual/ irregular frequency	Grazing, Agriculture. Hunting, Charcoal, honey, ticks	Moderate	Sensitive
	Montane evergreen scrub	Annual	-	Moderate	Low sensitivity
Moist Afromont-ane forest (MAF)	Moist evergreen forest	Irregular frequency (5 years)	Agriculture, wild honey	High	Extremely Sensitive
	Low land semi-evergreen forest	Annual	Honey, hunting, access to fuel	Low-moderate	Low sensitivity
***Combretum-Terminalia* woodland (CTW)**	*Combretum-terminalia* broadleaved deciduous woodland	Annual	Agriculture/grazing, Ticks, Honey, Hunting, Charcoal	Low	Low sensitivity (adapted to fire)

alter species composition (Ericksson et al., 2003). The study further revealed that unlike dry Afromontane forests, *Acacia* woodland is a fire-prone and fire resilient ecosystem, due to differences in microclimate, fuels, fire behaviour, and bark thickness of the dominant species.

There is a general consensus among experts that most of the forest fires in Ethiopia are induced by humans, hence of anthropogenic origin (Teketay, 2000; Bekele and Mengesha, 2001; Johansson et al., 2019). The lack of dependable and long-term data on fire statistics especially on occurrences and impacts as well as on causes have made the task of developing an appropriate fire prevention and management system a difficult task. The causes for human induced fires include illegal charcoal making in woodland/forest areas, burning of agricultural residues, use of fire in the process of honey collection in forests and in land clearing or when people deliberately set fire in conservation areas, i.e., arson (Belayneh et al., 2013).

Our knowledge on the causes, occurrence and distribution of forest fires and the sensitivity of the different forest ecosystems is thus based on observational reports and few field studies. Expert analysis of the major causes of fire in different vegetation types in Ethiopia was conducted by a panel of stakeholders from different organizations during a round table conference on fire two decades ago (see Table 13 below). The analysis revealed the diversity in fire sensitivity of the different vegetation types and the role of human activities in fire prevalence across vegetation regimes. However, given the dynamics in the socio-economic and demographic conditions in the last two decades, it is important to investigate the validity of causes identified in Table 13 (see page 53).

Tables 14 and 15 present findings from responses of experts to questionnaires from six regional states - Afar, Benishangul Gumuz, Gambella, Oromia, and SNNP and Somali regions.

Table 14: Responses of regional experts on wildfire frequencies cause and impacts

Regions	Fire frequency	Cause	Impacts
Afar	Occasional (not annual)	Anthropogenic	Forests impacted, no documented data
Benishangul Gumuz	Seasonal (annual)	Anthropogenic	Forests impacted, no documented data
Somali	Occasional (not annual)	Largely anthropogenic	Forests impacted, no documented data
Gambella	Seasonal (annual)	Largely anthropogenic	Forest and wild animals impacted, no documented data
Oromia	Seasonal (annual)	Anthropogenic	6000 ha in 2020; 1500 ha in 2021/22
SNNPR	Seasonal (annual)	Anthropogenic	15,277 ha in 2020; 2326 ha in 2021/22

Table 15: Responses of regional experts on the relative importance of major causes of forest fires

	Agricultural expansion	*Charcoal making*	*Improved pasture*	*Honey collection*	*Hunting*	*Conflict*	*Fending off wild animals, and livestock parasites*
Afar	2nd	1st	-	-	-	3rd	-
Benishangul Gumuz	1st	2nd	-	4th	3rd	-	-
Somali	-	1st	2nd	-	-	-	-
Gambella	2nd	4th	-	3rd	1st	-	-
Oromia	1st	-	2nd	3rd	-	-	4th
SNNPR	1st	-	2nd	4th	-	-	3rd
All regions	**1st**	**2nd**	**2nd**	**3rd**	**-**	**-**	**-**

Across regions, fires are predominantly anthropogenic in origin and occur annually in most regions. On the other hand, despite variations in the relative importance of the major causes of wildfires in different regions, agricultural expansion was identified as the most important cause, followed up with charcoal making. The latter is number one driver in the lowlands (Afar and Somali Regions) compounding the effect of use of fire in rangeland management in the lowlands of southern Ethiopia.

Though we lack statistics on wildfires in Ethiopia, it is believed that wildfires are becoming a serious threat to Ethiopia's forest resources in the drylands due to increased frequency and intensity. Every year, just before the short rainy season, large areas of western and south-western woodlands and grassland formations are affected by fires. Natural fire incidences have been common for long time as a result of an ecological fire cycle, though the role of humans is believed to have been growing over time. Apart from the natural fire cycle in dry lowlands and midlands, there has been an increasing incidence of fire in forest ecosystems with little or no previous fire history. The situation is further exacerbated by the changing climate and extended dry seasons, and encroachment of settlements into forested areas.

Cases in point are the wildfires in Wof Washa Forest in 2021, in Simien National Park in 2019, 2021, and 2023, and in Yayu Biosphere Reserve in 2013. The fires of 2000 had affected large forest areas in Bale, and affected woodlands and grasslands in Borana, Awash National Park, Nechsar National Park and parts of eastern Hararghe. The Bale mountains experienced repeated wildfires in 2007 and 2008 (Getahun et al., 2013). Following the disastrous wildfires of 2000, Ethiopia hosted an International Round Table Discussion on Forest Fires, organized by the Ministry of Agriculture, and supported by GIZ and GFMC (MoA, 2000). The Round Table provided important recommendations for the development of medium and long-term fire management programs that would lead to putting in place a national wildfire management strategy that would become part of a larger national forest and land management plan.

However, government efforts were limited to some awareness creation campaigns and training, the initiation of fire-fighting task forces in a few fire prone areas, and the development of fire management manual. Encouraging results were observed however, particularly in recognizing the role of community mobilization for firefighting in some areas. International collaboration was also helpful, especially in providing support for forest fire hazard information and in providing fire-fighting training (MoA, 2000, GFMC, 2019). Nonetheless, after two decades, Ethiopia's responses to recent fire incidences demonstrate that the recommendations of the round table have not been fully implemented, and a national fire management system in Ethiopia is urgently needed.

Though forest fires are strongly linked to weather conditions, with periods of drought increasing their prevalence and potential damage, studies on the impacts of climate change on forest fires and other hazards such as outbreaks of pests and diseases are limited (FDRE, 2015). Given the projected increase of fire probabilities in large parts of Ethiopia, the comparative response of species to fire will also be a crucial factor in governing future vegetation developments (Hoffmann et al., 2003; Geiger et al., 2011). Human activities have also influenced fire patterns at different spatial and temporal scales, causing fires to disperse into areas where resources and conditions would not typically support them (Lavorel et al., 2006). In regions with high natural fire frequencies, human activities may alter fire activities (Bowman et al., 2011; Sa' et al., 2011). Understanding future fire regimes across vegetation types requires taking into account spatial non-stationary fire–environment relationships (Sa' et al., 2011) and the stochastic nature of fire occurrences (D'Odorico et al., 2006, 2007) in modelling projections of future fires.

Climate change projections for eastern Africa point to an increase in annual mean temperature. Projected higher temperatures and extended drought conditions coupled with population growth are likely to increase the occurrence and intensity of wildfires in the region in the future (Kayijamahe and Otieno, 2020). A modelling study by van Breugel et al. (2016) in Ethiopia looked into the role of fire in driving potential natural vegetation distribution, and the impact of predicted fire regimes under climate change scenarios on future vegetation distribution. The study showed that there is clear correlation between distribution patterns of fire and major vegetation types in Ethiopia. Moreover, despite differences among climate change models and scenarios, a general trend in expansion of fire in moist Afromontane forests and *Combretum-Terminalia* woodlands is expected. Interestingly, apart from predicting an increase in fire prone areas, the inclusion of fire in the modelling prediction of future vegetation distribution revealed stronger expansion of *Combretum–Terminalia* woodlands and a more limited increase of moist Afromontane forests.

Given the impact of fires on remnant forest blocks and key biodiversity hotspots with national and global importance, notably in the Bale mountains, Siemen National Park and Yayu biosphere reserve, the threats posed by wildfires warrant urgent national action. Moreover, given the role of forests in building Ethiopia's climate resilient green economy, the absence of a national wildfire management system seriously undermines the ability of Ethiopia's green growth policies, strategies and initiatives to meet their desired goals.

3.2 Traditional fire management practices

Large extent of African landscapes has evolved through frequent, low-intensity natural fire regimes that contributed to the evolution of varied savanna grasslands and mixed bush and woodlands (TerrAfrica, undated). In addition, the deliberate use of fire as a land management tool has a long history by local communities in rangelands, dry woodlands and moist grasslands of the Afromontane regions (Findlay et al., 2022). Communities use fire to modify vegetation and landscapes for their benefit (Butz, 2009, Archibald et al., 2013) and to reduce burden of ticks and other parasites, to fend off reptiles and predators, to control encroaching shrubs, to remove litter and rejuvenate grasses and to facilitate livestock movements, in addition to benefits stated earlier (Solomon et al., 2007; Angassa and Oba, 2008; Butz, 2009; Trollope, 2011). According to Myers (2006), "fire management refers to the range of planned actions (technical and management decisions) meant for preventing, detecting, controlling, containing, manipulating or using fire in a given landscape to meet specific goals and objectives."

In Ethiopia, use of fire as a rangeland management tool is commonly practiced the rangelands of Borana (Angassa and Oba, 2008; Ebro and Mengistu, 2015) and Guji Zones of Oromia (Abate, 2016), and in the lowlands of Gofa Zone, Afar (Tilahun et al., 2016), as well as in Somali Region (Zerga et al., 2018), and by Nuer pastoralists in Gambella Region (Tilahun et al., 2015). Traditional fire use has also been practiced in the Afroalpine vegetation zones and the bush lands of south-eastern Ethiopia (Angassa and Oba, 2008; Johansson et al., 2013), and the western lowlands (Gudesho and Woldu, 2021). Apart from the rangelands of lowland areas, regular and controlled patch burning had been used by agropastoralists in the humid highlands of the Bale Mountains (Johansson et al., 2023, 2019). In addition, slash and burn farming is practiced the lowlands of western Ethiopia in Benishangul Gumuz Region (Terefe and Kim, 2020; Gudesho and Woldu, 2021). In these systems, while the use of fire removes primary forests for agriculture, it also contributes to the subsequent development of secondary forest by breaking seed dormancy of certain species (Gudesho and Woldu, 2021).

The traditional use of fire by local communities is based on community's knowledge (Dalle et al., 2005). Traditional ecological knowledge is an integral part of local knowledge systems for environmental classification, assessment, resource use and management (Bollig and Schulte 1999; Godgil et al., 2000; Mapinduzi et al., 2003). Indigenous knowledge for sustainable resource management is acquired through observations over centuries (Dalle et al., 2005) regarding the influence of planned fire on the availability and dynamics of resources to suite the economic and socio-cultural needs of the community. One well-documented traditional use of fire in rangeland resource management is that of the Borana rangelands (See Box 1) (Angassa, 2007), until a prohibition of fire interrupted the practice.

A directive issued in the 1970s banned traditional fire use in the country, including in the rangelands (Coppock, 1994 cited in Coppock et al., 2007), though enforcement of the ban in practice has varied from place to place. Observations indicate that fire is being used, albeit discreetly (e.g., in Benishangul Gumuz and Gambella) which raises questions on the level enforcement of the ban. However, given the traditional role of fire in rangeland resource management, some also question whether the ban was not intended for rangelands like Borana but applicable on forest lands, and that authorities might have misinterpreted the ban (LaMalfa et al., 2008; Abdu and Robinson, 2017). Several reports indicated that the fire ban is a key factor that has contributed to rangeland degradation due to increased bush encroachment and reduced productivity (Dale et al., 2005; Angassa, 2007; Abdu and Robinson, 2017).

Despite the widely held view that fire use invariably results in degradation of many ecological systems and thus the need for fire-suppression policies, research findings from western Africa wooded savannas revealed that controlled seasonal burning is essential for enhancing plant biodiversity, and that it lessened the impact of subsequent fires (Mbow et al. 2000; Laris, 2002). In Ethiopia, the introduction of government policies which fail to take into account fire ecology and traditional knowledge in environmental resource management have been implicated for the expansion of unsustainable land use and subsequent rangeland degradation (Angassa and Oba, 2008; Pavanello and Levine, 2011). For example, a study on annual fire regimes inside and outside Bale Mountains National Park found greater fire size and intensity inside the park than outside. The findings of the study showed that strict enforcement of fire exclusion policy inside the park over the past 50-years, compared to the regularly ignited and less monitored areas outside of the park, contributed to a higher fuel build-up inside the park, which in turn amplified fire size and impact of wildfires (Johansson et al., 2019). These studies reasoned that fire exclusion policies need to be updated and should reflect fire history (Johansson et al., 2019), the importance of integrating controlled traditional burning, and the use of community-based fire management programs in landscape management (Johansson et al., 2019; Gil-Romera et al., 2019).

In summary, local ecological knowledge plays key role in traditional fire use in management of rangelands and other fire-adapted ecosystems. The introduction of government policies such as the fire ban not only failed to achieve the intended goals, but in fact, contributed to the degradation of rangeland resources and Afromontane ecosystems, and undermined the livelihoods of pastoral and agropastoral communities. These observations warrant the need for evidence-based policy interventions to achieve socially and environmentally sustainable landscapes. For this, a deeper understanding is needed of ecosystem-specific ecological processes such as fire history, and community-based fire management approaches, to better inform policies and develop an integrated fire management system.

Box 1: Oral history of traditional fire use in Borana rangelands (Source: Angassa, 2007)
Borana pastoralists have a traditional livestock production and resource management system, based on knowledge of seasonal availability, and with the aim of regulating access and use of water and pasture through controlling livestock mobility. A key traditional management practice in this regard is the use of fire. Burning of selected pasture areas was traditionally part of the rangeland management toolkit of the Borana (Abdu and Robinsons, 2017). It is used for improving pasture productivity and quality, and to suppress bushes, ticks, and predators. Rangeland burning was conducted during the long dry season before the main rainy season starts, when dry biomass accumulation is high. The frequency of ignition depended on fire histories and annual burning cycles. A 3-year burning cycle was reported as common, while some Borana pastoralists practices more frequent (2-year) or less frequent (5-year) burning. The use of fire is avoided in time of critical livestock feed shortage, and certain precautions are believed to be used when using fires in rangelands around settlements. Post-fire grazing regulations ensure the fallowing of parts of the pasture for some time. Traditional fire use combined with regulated livestock grazing was considered as an ecologically sustainable pastoral system. According to oral history records, Borana pastoralists perceived that their traditional management was effective enough for addressing local community needs while maintaining the ecological health of the rangelands. While the fire ban criminalizes the setting of fires, the subsequent increase in demographic pressure, adoption of unsustainable land use, and emerging challenges of climate change, have resulted in the degradation of rangelands in Borana, and the loss of the associated traditional knowledge. Bush encroachment has since severely affected the availability of fodder and livestock production on which livelihoods of many depend.

3.3 Prescribed fire

There is little documentation on historical practices of controlled/prescribed fire in Ethiopia except in the case of pastoral areas that largely bases on local knowledge (Angassa, 2007; Johansson et al., 2019). Historically, prescribed fire (though not strictly comparable with the modern concept of the term) has been widely practiced as a rangeland management tool in southern Ethiopia and particularly in the Borana rangelands (Dalle et al., 2005; Angassa, 2007; USFS, 2011). In the contemporary sense of the term, "Prescribed fire is the application of carefully controlled burns under defined fuel and weather conditions to meet land management or ecological objectives involving a written plan" (Myers, 2006). Prescribed fires are usually meant for achieving desired effects in both the short and long term (Myers, 2006), and are gaining acceptance in contrast to decades of policies in favour of fire suppression. Prescribed fire is highly efficient and economical in reducing surface fuels, removing ladder fuels, and increasing crown base height (Casals et al., 2016; Fule, 2002) that all contribute to reducing fire risk, especially in fire adapted ecosystems. Examples of historical settings and changes that followed the fire ban in Ethiopia is presented in Box 1 (Borana rangelands) and Box 2 (Bale Mountains heathlands).

After more than five decades of fire ban in Ethiopia, there is little or no information on the use of prescribed fire in Ethiopia. The only information in this regard is from a technical support project by USAID/USFS that demonstrated the use of prescribed fires in the Borana rangelands starting in 2005 (Gebru et al., 2007; USFS, 2011). The project aimed to address the problem of increased bush encroachment and the associated decline in pasture availability. It was initiated as a pilot project to test the feasibility of prescribed burning with the involvement of government and non-government actors and local communities (USFS, 2010). Encouraging results from early pilots led to scaling up as part of the USAID Pastoral Livelihood Initiative (PLI) (Gebru et al., 2007). This multi-year project generated useful lessons on the importance of prescribed fires in controlling bush encroachment and improving pasture productivity. Moreover, it provided capacity building through hands-on training to local experts on prescribed fire safety, planning, operation and monitoring, and developed guidelines for administering prescribed fire (USFS, 2010).

Based on evidence from the field, project proponents in collaboration with local government agencies formed a stakeholder alliance and lobbied for a revision of the 1970s fire ban (Coppock et al., 2007). Their efforts led to the lifting of the ban in 2005 in Borena (Pavanello and Levine, 2011), but subsequent attempts to scale-up use of prescribed fire on communal rangelands faced another stumbling block. In prescribed burning, fire can be started and maintained only when there is enough dry grass underneath the bush cover. Nonetheless, rangelands are currently characterized by limited and patchy grass cover which may not provide the required fuel to sustain fires and to result in burning of shrubs. Also, the scarce grass is in high demand by pastoralists owing to declining pasture quality and overgrazing (Pavanello and Levine, 2011; Abdu and Robinson, 2017).

However, it is worth noting that the fire-ban disrupted customary rangeland resource management institutions and contributed to bush encroachment and subsequent rangeland degradation. Additional drivers included demographic and climatic factors that exacerbated rapid land use changes in the rangelands. While the effort towards re-instituting prescribed fire is commendable, it appears that the socioeconomic and biophysical changes that have occurred now necessitate a suite of interventions to restore rangelands.

It is not clear if the lifting of the fire ban is unique to Oromia Regional State or not. Other regions are expected to follow suite and make policy revisions accordingly. In fact, bush encroachment is a widespread problem in most rangelands, either of native *Acacia* amongst other species as in Borana, or the exotic *Prosopis juliflora* that has become an invasive bush having encroached large tracts of rangelands in Afar, as well as in Somali region, and in parts of Oromia and SNNP Regional States.

Box 2: Changes in traditional fire use and management in Bale Mountain heathlands (From Johansson et al., 2019)

Historical fire use practices - Traditional patch-burning and free-range grazing were common practices across the subalpine heathlands of the Bale Mountains before the establishment of the Bale Mountains National Park (BMNP) and the introduction of a national ban on fire. Traditionally, fire was used to increase pasture quality, get rid of insect pests, and minimize livestock loss to predators. Burning was done collectively by several men across villages in a controlled fashion. Fire was initiated by line ignition of many shrubs simultaneously down-slope of a 'mature' (8–14 years old) stand, to make an upslope high-intensity crown fire. Fires were perceived to produce better pasture and reduce the size of remaining stumps that restricted cattle access. Annual burning started in December and January. In those days, extended droughts were rare, and fire use often led to only the intended impacts.

Current fire use practices - Igniting fire elsewhere in the heathlands is an illegal activity and anyone setting forest fire faces imprisonment. Settlers inside the park are under stronger scrutiny than those outside the park. Traditionally, communities use fire to manage rangelands, owing to the ban, ignition is not done openly. It is also rare for people to inform of fires to the authorities. Neither ignition is started by community members simultaneously or in a concerted fashion as in the old days. Rather, ignitions are initiated by individuals randomly and discreetly, and often later in the dry season as quick ignition requires drier vegetation. Given relatively strong monitoring inside the park, ignition frequency in the park is lower than that outside the park. Moreover, ignition timing inside the park is late in the dry season while outside the park it is done whenever it is possible. As a result, increased ignition frequency outside the park has decreased fire sizes compared to those inside the park. In spite the fact that the objectives of fire management in the heathlands remain the same, practice changed in response to the restrictions following fire ban, thereby altering fire use procedures and disrupting the fire regime that negatively impacted the resource base.

3.4 Responses to wildfires

As noted previously, Ethiopia's responses to wildfire incidences have been inadequate, poorly coordinated and failed to be pro-active. Most took the form of emergency responses that lacked required preparedness and proper coordination for mobilizing available resources.

A key factor was the absence of a functional forest fire management system. Some forest fires in Ethiopia (in 2000, 2008, 2019 and 2021) received media attention, and managed to attract responses from the government and international partners. In the sections below, the nature of Ethiopia's responses to forest fire incidences is evaluated using the three stages in forest fire management: preparedness/reporting, response effectiveness, and post-fire lessons. The responses described below were collated from various sources including literature and reports from government, the media and other sources.

Preparedness/reporting: The fire season in much of Ethiopia generally overlaps with the late dry season (December to April). Accordingly, an organization responsible for forest fire management is expected to provide early-warning information for all concerned actors at different levels before the onset of the fire season. Such information when delivered in time would allow better preparation for detecting and controlling wildfires. A good example is annual alerts that the Ministry of Agriculture and Disaster Risk Management Commission (DRMC) provide on risks associated with delayed or extended rains (drought and floods) that affect agriculture. These alerts are broadcast on national media, largely based on forecasts from meteorological data. In the context of forest fires, it is unfortunate that Regulation No. 363/2015 that established the National Disaster Risk Management Commission has not explicitly included forest fires as a major disaster risk. The Ethiopian Forestry Development is expected to lead efforts in forest fire management by providing early warning information to facilitate preparedness of sub-national actors, amongst other actions. EFD already began collating web-based information and disseminating same to regional actors (Anonymous, 2022). It is not clear however how long and how often has EFD been providing early warning information to regions, and how Regions have been using this information. Reports on Ethiopia's responses to large scale fires reveals that relevant actors from local to national level were poorly prepared (Goldammer and Abbgerger, 2000). Though there exist some line of reporting of fire incidences and the conditions for requesting higher level assistance (MEF, 2014), it is not clear what are the conditions that should be met and procedures to be followed to make such requests. The absence of operational protocol for fire incidence reporting and a delay in information flow (from lower to higher levels) have contributed to poor coordination amongst actors and delays in mobilizing resources to facilitate implementation of timely responses (Anonymous, 2022).

Response effectiveness: According to the forest fire management manual produced in 2014, local level actors (kebele administrations) are responsible for initiating the first response to wildfire incidences in their jurisdictions through the mobilization of available resources (logistics and personnel). The same document further outlined that lower-level actors should request assistance from the next higher level when the firefighting situation is beyond local level capacity. At times, relevant departments at federal level become aware of a fire incidence in a given locality through media reports (Anonymous, 2022). This response arrangement is inherently flawed given the limited capacity for fire management at different levels, resulting in delayed responses which in turn results in extended burning. It is also important to note that federal level actors should also proactively predict and detect wildfires,

Table 16: Timeline of fire management responses to the 2000 forest fires (Source: GFMC, 2000)

No record	**Fires incidence first observed by local actors in Oromia region**
18 February 2000	Ethiopian Federal Ministry of Agriculture (MoA) received reports that uncontrolled forest fires had started in different parts of the country
18 February	MoA launched two reconnaissance surveys to more accurately assess the situation.
20 February	The local GTZ forest advisor contacted the GFMC and described the situation.
23 February	MoA received detailed reports on two large forest fires in Oromia Regional State
End of February	About 600 ha of the Afroalpine vegetation in the Bale Mountain's National Park had burnt
27 February	GFMC produced and shared a fire situation report calling for assistance of fire specialists and government authorities in South Africa, Namibia, Zimbabwe and Ethiopia
	The government of Ethiopia requested for assistance from South Africa, but their helicopters were engaged in emergency operations in flood-stricken Mozambique
1-5 March 2000	Start of the international response
2 March	A fire specialist brought to Ethiopia through GFMC produced the first situation analysis by GFMC-GTZ that was submitted to the government of Ethiopia (GoE).
6-9 March	An International Fire Emergency Advisory Group including experts from Ethiopia, GFMC, Germany, South Africa and the USA was formed, and Incident Command System was set up.
10 March	A spotter plane from South Africa arrived in the afternoon, and later that day, 15 firefighters arrived from Johannesburg.
11 March	Fire fighters were sent to Goba Base Camp where they were joined by 15 Ethiopian soldiers.
12-13 March	A pilot trainer, technician and four additional crew leaders arrived, and helicopter-based firefighting crew became fully operational in Bale Zone.
14 March	A shipment of 320 backpack water pumps from Germany arrived by special airfreight.
15 March	GFMC approached UNEP and suggested a cash donation to ensure the continuation of the South African firefighters.
17-21 March	The GoE officially requested UNEP's assistance, and UNEP donated US$20,000
	GFMC discussed the possibility of a contribution from the UK to upgrade the capabilities of the Ethiopian Remote Sensing unit for fire detection.
	271 fire fighters (community members, militia, etc..) were trained in firefighting techniques
24 March 2000	Fire incidences which erupted on 22 March in Nechisar, and Awash National Park were contained after an estimated 10-15% of the park area had been burned.
30 March 2000	The number of civilians and soldiers that were trained in firefighting techniques totals 755
26-31 March	Heavy showers (short rainy season) reported in all affected areas
7 April 2000	All fires are under control

rather than passively waiting to be officially informed by sub-national authorities. Responses to the 2000 forest fires demonstrated gaps regarding Ethiopia's capacity to respond effectively. These included that the country lacks the capacity to suppress large-scale fires as international assistance was required to play a pivotal role. There was a serious gap in information flow, logistics, firefighting equipment and skilled personnel, and the delayed response increased the loss of forest resources. There was no post fire assessment of burned areas, so the extent of the impact of these fires remains unknown. An important observation from the 2000 fire response is the need for clarifying and improving forest reporting mechanisms from lower to national levels, and the need for strengthening collaboration with important external actors, notably the Global Forest Management Center (GFMC). The support they provided during the campaign demonstrated the importance of a future partnership with GFMC and other actors to building national capacity for improved response in the future.

To understand what happened in the 20+ years since the 2000 fires, and to build Ethiopia's capacity to respond, it is useful to assess the country's response to the fires that affected Simien and Bale National Parks in 2019, and the Simien National Park and Wof Washa protected forest in 2021. Although no assessments on burned areas or impacts are available, these fires seemed less severe and were limited in extent but impacted highly important conservation areas. Unlike the 2000 fires however, there is no organized data on the whole response process. Based on available information from different sources, the overall response process to the 2019 forest fire in the Siemen National Park is collated below as an indication of current capabilities.

Fire reportedly started on 26 March 2019 in the eastern part of the Siemen National Park. The fire had been raging for five days before local firefighters (farmers, local authorities and 500 volunteer youth) appeared to have it under control until renewed fires started on 9 April. A federal and regional government committee visited the area on 12 April and external intervention was sought to combat the crisis (GFMC, 2019). The government requested international assistance for firefighting helicopters from Kenya and South Africa. But this was not successful. Prime minister Abiy Ahmed then called his Israeli counterpart for assistance and a team of expert firefighters, and a helicopter arrived. The fire was under control in the third week of April. At least 342 ha of the park area was heavily impacted in the first five days, and the fire later damaged additional areas (Addis Fortune, 2019), though the total burned area was never reported. Earlier, in January 2019, a wildfire in Bale Mountains National Park lasted more than 20 days and damaged 2,600 ha.

Post-fire actions: A notable undertaking following the 2000 wildfires was the International Round Table discussion that took place in September 2000. This sled to the identification of lessons and challenges of fire management in Ethiopia that will be instrumental during the development of a national fire management system. Based on the 2019 fire responses, two key questions arise. 1) What were the lessons that Ethiopia learned from firefighting experiences in 2000 and 2008? 2) How better prepared and equipped was Ethiopia in responding to the wildfires in 2019 and 2021?

Table 17: List of actors involved in forest fire response and their roles

Federal level entities	**Roles**
Ministry of Agriculture (MoA)	Coordinating national efforts and collaboration with international partners (as in the 2000 fires)
Ethiopian Forestry Research (EFD), formerly the Environment Forest and Climate Change Commission (EFCCC)	Coordinating national efforts in fire management emergencies, forest protection and development
Ethiopia Wildlife Conservation Authority (EWCA)	Managing the National Parks; directly involved in fire management in national parks
Disaster Risk Management Commission	Conducting risk assessments and overall coordination of responses
Higher level Political Authority (PMs Office)	Providing political support, also in soliciting external assistance
The National Army	Engaging in firefighting campaign
GIZ	Linking MoA with GFMC, soliciting support from donors (Germany)
GFMC	GFMC coordinated international support and the firefighting process, facilitated in-country training.
Other countries/development partners (South Africa, Israel, USA, GFMC)	Various countries provided firefighting experts, planes and helicopters
Sub-national entities	
Regional militia	Engaging in firefighting campaign within their jurisdiction
Regional Bureau of Agriculture	Coordinating firefighting campaigns in the regions
Regional administration	Providing political support and overall guidance for mobilization and coordination of the response process
Regional entity on forest protection	Providing technical guidance and coordinating response processes
Zonal and woreda level relevant government offices	Providing support and coordination in the response process in their respective jurisdiction
Kebele administration	Responsible for initiating firefighting responses at kebele level
Local communities	Actively engaging in firefighting campaign
National park managers	Managing national parks and responding to fire incidences within their jurisdiction
Academia	Providing technical support and initiating the mobilization of students for firefighting
Civil society organizations	Providing technical and financial support for fire emergencies

Actors in forest fire management: Despite the absence of a properly organized and coordinated forest fire management system, the foregoing reveals that a number of actors were involved in fire emergencies in the past (Table 17). These participated in the response process in different capacities and at different levels, and their identification and assessment of their importance is essential, as this helps in informing the development of an appropriate national fire strategy.

In summary, Ethiopia lacks a system capable of monitoring fire hazards, suppressing fire incidences to reduce impacts, and above all, the capacity to effectively manage future forest fires. It further reveals that the current system is fragmented, poorly coordinated and under resourced in terms of information, data, human resources and logistical capacity when it comes to predicting and effectively controlling wildfires. On the other hand, the 2014 National Forest Management Manual is a valuable document to build upon, providing key elements for putting in place institutional arrangements for forest fire management, relevant tasks related to fire incidence reporting, mobilizing firefighting personnel and resources, coordinating actions and post-fire management.

3.5. Policy instruments and legal framework

There are a number of national policy and legal frameworks that support sustainable forest management and use to achieve Ethiopia's environmental, social and economic goals (MEFCC, 2018, a,b; FDRE, 2021). Most stress lack of political will and limited capacity in implementing these instruments. One major gap in this respect is the lack of a national land use policy and plan that determines land use types and governs procedures in land use changes. The Federal Rural Land Administration and Use proclamation (Proclamation No. 456/2005) and the related regional legal frameworks are the only instruments for regulating land management and use. The review of national policies, strategies and plans in relation to wildfire protection and control provides an insight to identify enabling policy space and barriers and gaps that need to be considered in developing a national forest fire management system. The analysis is supplemented with information gathered using KIIs and feedback obtained during the consultative workshop with stakeholders.

Nationally Determined Contributions (NDCs): This states Ethiopia's ambition to reduce GHG emissions by 2030. The updated NDC (FDRE, 2021) clearly identified forestry as key sector, which has 85% of the emission reduction abatement potential through sustainable forest management and forest development. The NDC further identified the role of forest resources in climate change adaptation, and the need for the implementation of appropriate strategies to protect 17.2 million ha of the country's forests from fire, pests and diseases. Therefore, as an overarching national plan, the NDC provides an enabling environment for putting in place forest fire management system as part of the national forest sector development program issued in 2018.

Forest Development, Conservation and Utilization Proclamation (2018): This provides the legal framework for forest development and management. Section 8 (Miscellaneous

Provisions), Article 21 is particularly relevant to preventing forest hazards, and the first six issues focus on forest fire prevention. The proclamation provides general guidance on the role of different actors in reporting, preventing, and suppressing forest fires. Specifically, the article identifies the need for capacity building and establishing an early warning system; that the necessary precaution needs to be taken in preventing forest fires; that all actors have the duty to report wildfires and government, NGOs, private actors and communities have the responsibility to participate in firefighting; that different administrative layers shall mobilize and coordinate firefighting campaigns; and that the forestry agency is assigned as the responsible body to coordinate fire responses nationally. The proclamation provides a conducive policy environment for wildfire protection, but barriers remain in realizing the stated tasks. Importantly, it lacks a regulation and detailed guidelines and procedures regarding how provisions in the proclamation could be implemented on the ground, and who will be implementing these tasks using what resources. Integrating forest fire management into forest management plans and putting in place a forest fire management system with well-defined coordination, implementation and financing mechanism are tasks yet to be accomplished.

National Forest Sector Development Program (NFSDP): NFSDP was issued in 2018 and is considered by many as an important document that serves as the roadmap for forestry actions between 2018 and 2025 and facilitates collaboration across sectors at national and sub-national levels (MEFCC, 2018b). The program has a direct bearing on forest fire prevention and control and can be considered as an enabler for the development of a forest fire management system. NFSDP identified frequent fire incidence as a challenge to the country's forest resources; recognized the absence of a well-organized, well-equipped and adequately financed system in responding to forest fires; identified the need for establishing early warning systems for fires and forest management plan that employs protection measures against uncontrolled fires; and recommended the development of a forest emergency services including forest fire and recognizes the need to build Ethiopia's firefighting capacity in terms of logistics and skill.

National REDD+ Strategy: This strategy was issued in 2018. It identified the major drivers of D&D and spelt out strategic interventions to address them. Wildfires were identified as among the major drivers of deforestation that also result in increased carbon emissions (MEFCC, 2018a). it also identified the agents and causes of forest fires and the spatial distribution of fire incidences (regional states where forest fires are more frequent). The strategy put forth strategic actions to be undertaken to prevent and suppress wildfires, including capacity building, among others.

Federal Wildlife Development, Conservation and Utilization Proclamation (Proclamation No. 541/2007): This has no provision that explicitly refers to the protection of wildlife habitats in general or issues related to natural/man-made disasters like wildfires. However, the Council of Ministers Regulations No. 163/2008 for the implementation of this proclamation has provisions that prohibit setting fire in protected areas and use of fire for wildlife hunting. A key informant interview with a wildlife expert at the Ethiopian Wildlife Conservation Authority (EWCA) revealed that EWCA had put in place a wildfire prevention and protection strategy that focuses on raising awareness of communities around protected areas on impacts forest fires, on establishing community fire brigades around parks, and on constructing fire breaks. EWCA has been piloting its strategy in Kafta Sheraro and Bale Mountains national parks and began sharing early warning wildfire hazard information to better prevent fire. EWCA reportedly faces financial constraints to scale out and fully implement its strategy. EWCA also needs to align its strategy with relevant institutions in this regard, such as EFD for forest fire management, and with the Disaster Risk Management Commission with mandate to deal with disasters.

National Policy and Strategy on Disaster Risk Management: The national policy and strategy to managing disaster risks was issued in 2013 and the mandate was given to the Disaster Risk Management Commission. The policy document assigns sector institutions to be lead actors in addressing hazards relevant to the sector. In addition, it recommends that devolved institutional arrangements shall be put in place for every hazard at Federal, Regional, Zonal and Woreda levels. This implies that at Federal level EFD shall be responsible for coordinating responses to "forest and bush fire", which the document identified as a disaster risk. Two principles stated in the document have direct relevance to forest fire management: "Special attention to natural resource and environmental development and protection" and "Disaster risk management shall be decentralized and community centred." The latter is particularly important as it promotes a devolved institutional arrangement for wildfire management that in turn facilitates active participation of communities in forest fire management. The policy and strategy clarified on what a "declaration of disaster" means, and how an official announcement as a 'disaster', will be made by the national Disaster Risk Management Council to request support from other entities.

The Federal Rural Land Administration and Use Proclamation: This proclamation, commonly known as the 2005 Land Law, is the overarching national legal instrument that guides rural land administration and use (FDRE, 2005). Regional laws on rural land administration and use must be consistent with the federal proclamation. Generally, it is highly skewed towards rural land management in the highland areas where sedentary framing is practised. Many criticize the law for being less relevant to pastoral and agropastoral framing systems even though it clearly states that pastoralists and agro pastoralists have rights to have free access to land. The law does not mention whether customary laws and institutions are legal or not whereas these play important roles in governing access to and use of land. Only the regional land law in Afar gives responsibility of managing pastoral land resources to customary institutions, but it also gives similar responsibility to woreda and kebele administrations (Temesgen and Gebru, 2015). The implication of these legal instruments is that traditional land management practices including prescribed fire in pastoral areas lack legal backing. This, coupled with weakened traditional institutions, is believed to be contributing to the degradation of rangelands (Ebro and Mengistu, 2015).

3.6. Institutional arrangements and coordination mechanisms

The 2014 forest fire control and prevention manual issued by the then Ministry of Environment and Forests (MEF) identified key stakeholders that should be involved in forest fire management activities at federal, regional, zonal, woreda and local levels. It further assigned roles and responsibilities of individual stakeholders and the coordination mechanism to be used in the event of a forest fire. However, it is not clear to what extent this institutional arrangement was made operational. In practice, EFD and EWCA have been the two national actors at the forefront of forest fire responses in the country, and there is little information on the level of engagement of other actors. In fact, the response mechanism to recent forest fire incidences involved other high-level federal level actors like the DRM Commission and the Prime Minister's Office (PMO) that were not stated in the institutional arrangement described in forest fire management manual.

The existing institutional arrangement and coordination mechanism appears to be rather weak and fragmented. A permanent operational arrangement or platform is lacking. According to workshop participants, there is no well-established and permanent coordination mechanism in most regions, except in Oromia and Benishangul Gumuz. The response mechanism is generally based on an ad hoc institutional arrangement that responds to forest fire incidence as an emergency.

Apart from the 2014 manual, there are no detailed guidelines or protocols at national level that describe instructions or operational modalities to be followed in predicting, preventing, detecting and controlling forest fires. There is lack of clarity as to which government institution, when and under what conditions, should request assistance from the next higher level, and how to declare forest fire as national disaster in the event of a major fire that proves difficult to control. How EFD and NDRMC interact on this matter has not been clear, even though it is the latter that has a mandate to declare a national disaster. On the other hand, the forest fire manual indicates that lower administrative levels can call for support from the next higher level when a given administrative level feels that the fire incidence is beyond its capacity to control it. But time limits for requesting support are not indicated even though time is clearly of the essence in managing forest fires. Given the limited technical and logistical capacity of lower-level administrations, their limited capacity to quickly assess the intensity and extent of a fire incidence, delays are expected in requesting assistance, which in some case may lead to delays in controlling fires with potentially huge subsequent impacts on forests and livelihoods. Equally concerning is the lack of established and clear procedures at federal level to assess fire intensity and extent, and when and how to request assistance from international actors (Anonymous, 2022).

3.7 Gaps and challenges

As stated in the earlier section, Ethiopia's overall capacity to predict, detect, report, and control forest fires in a timely manner has remained low. The key challenges in forest fire prevention, detection, suppression and post-fire restoration can be categorized into (i) policy and legal instruments, (ii) institutional set up, and (iii) organizational capacity (data, skills and logistics). The section below describes these challenges and proposes action areas to address them.

3.7.1 Policy and legal challenges

The following are the main policy and legal challenges that need to be addressed:

Lack of a national land use policy and plan: Despite calls for it and support by development partners, Ethiopia has not so far issued a national land use policy and plan even if some regional states are making attempts. The absence of a national land use policy remains to be a major bottleneck.

Lack of a national fire management system: There is no national fire management system in Ethiopia (Bekele and Mengesha, 2001; EFCCC, 2019; Anonymous, 2022) though legal provisions exist to penalise those who set fire in forests. The absence of a forest fire management system is central to the observed weak forest fire monitoring, preparedness, and prevention (Anonymous, 2022). Development of a fire management strategy was one of the key recommendations of an International Round Table Conference some more than 20 years ago (MoA, 2000), and this was identified as a key challenge by workshop participants as part of this study. Such a system needs also to consider the national and regional parks where fire has become a major concern. It should also be in line with policies and strategies of relevant sectors and encourage cross sectoral collaboration at all levels given the fact managing wildfires calls for multisectoral collaboration at all levels. It is important that fire management should become an integral part of the country's overall land-use policy and land management practices.

Lack of forest management plans: Despite efforts of successive forestry agencies (MoA, MEF, MEFCC, EFCCC, and recently EFD) in delineating forest areas and developing management plans, most of Ethiopia's forests remain without management plans (EFCCC, 2019). Fire management is often treated as an emergency engagement and is given little attention in forest management planning. The development of fire management plans as part of forest management plans is essential for effective forest fire preparedness, monitoring and prevention.

Weak law enforcement: Observational reports indicate that most forest fires are caused by people. Even though setting fire to natural forests is prohibited by law, traditional fire use continues to be practiced in the country. Moreover, arson is also a cause of fire incidences in and around protected areas, in some cases to show discontent as most parks do not have negotiated and agreed upon benefits sharing mechanisms with surrounding communities. There are few reports of punitive measures taken by law enforcement agencies, and weak law enforcement is often identified as a key gap in forest protection and in fighting human caused forest fires. According to key informants, weak law enforcement is a common challenge across all regions and is reported to be even more in some Regions (e.g., Benishangul Gumuz, Gambella, Oromia, and SNNP), although some improvements are being made.

3.7.2 Institutional gaps

Ethiopia still lacks an operational and permanent coordination mechanism from national to local levels to better manage forest fire risks. This is one of the key institutional gaps. Based on a review of the literature, key informant interviews and the views of workshop participants, the following gaps in coordinating actors and activities should be addressed for improved forest fire management.

- Lack of clarity on the roles of key actors in different sectors and administrative levels that should be involved in forest fire management system. For instance, despite their legal mandate in administering and managing most plantation forests in their respective regions, actors like Oromia Forest and Wildlife Enterprise (OFWE) and Amhara Forest Enterprise (AFE) seem to play little role in forest fire management in forests outside their mandates.
- The absence of well-defined and mutually agreed mandates for individual actors and coordinating entities at national and sub-national levels in forest fire management.
- Response mechanisms are based on fragmented coordination structures and there is weak alignment among levels. Well established institutional arrangements are lacking, for governing the overall coordination mechanism and ensuring full alignment of actors and activities in fire management at different levels of the government structure,
- Response mechanisms to forest fires have been based largely on ad-hoc arrangements. A fully operational and permanent institutional arrangement for coordination is still lacking. Thus, such arrangement needs to be put in place and made operational.

3.7.3. Capacity limitations

There is no documented information on the available capacity regarding forest fire management across relevant organizations or at different levels of government. But it does seem that equipment and trained staff are in short supply, considering the way forest fires were managed in the past. Available information from published and grey literature (e.g., MoA, 2000; Bekele and Mengesha, 2001; EFCCC, 2019; Anonymous, 2022) and information gathered through key informant interviews and the national stakeholder consultation workshop, emphasize the presence of huge gap in institutional (logistical, financial) and human resources (knowledge, skill) capacity at national and sub-national levels. Capacity gaps also relate to relevant data on forest fire incidences, causes, and impacts.

Data related gaps: The lack of systematically organized forest fire statistical data regarding incidence, distribution and impact (EFCCC, 2019) make it challenging to design and implement an appropriate forest fire management system. For example, the absence of data on fire risk undermines efforts to be prepared for impending fire danger (Bekele and Mengesha, 2001). Feedback obtained from experts in the regions indicates that the absence of data on fire trends is a key gap in predicting and preventing forest fires. In was reported by experts from EFD that the federal forestry agency has been building capacity (with the support of Italy's CIMA) with regard to early-warning system. EFD has built an online, real time risk assessment system called *myDEWETRA* to gather remotely sensed forest fire data and distribute it to regions in the form of bulletins. The lack of documented post-fire assessments makes it difficult to estimate fire impacts and to plan and implement restoration and rehabilitation activities.

Skills related gaps: The number of skilled personnel specifically trained in fire prevention, detection, monitoring, and suppression is difficult to obtain. The gap in skilled manpower is highlighted by key informants from EFD and from the regions. Ethiopia's response to previous fires demonstrated the challenge in relation to firefighting skills. The country had to call for international assistance from GIZ, GFMC and USDA on firefighting techniques (Goldammer and Abbgerger, 2000) and prescribed fire management (USFS, 2010). However, there is little information as to whether or how many of the trained staff are still in their posts.

Financial constraints: Apart from the limited financial support that EFD occasionally provided to regional actors for firefighting costs (Anonymous, 2022), there is no annual budget allocated to support fire management. The absence of a dedicated budget often makes overall planning and execution of fire management activities difficult, and undermines fire monitoring, prevention and suppression capability.

Logistical limitations: The lack of basic firefighting equipment (personal protective equipment, hand-tools, backpack sprayers), infrastructure (fire breaks, fire towers, forest roads), vehicles, aerial firefighting support (adapted helicopters) and monitoring technologies (drones) are notable gaps which limit the effectiveness of firefighting responses, especially in rugged and mountainous areas. The requests for external support in recent fire incidences demonstrated the prevailing gap in logistics.

3.8. Lessons learnt and good practices to build on

Lessons from past forest fire incidences have hardly been learned when it comes to reporting, coordination and financing, though there are lessons and practices on which the country can build on when developing a national forest fire management system. The following were identified from the literature, key informant interviews and feedback gathered from workshop participants.

EFD's early warning systems: The initiative by EFD to use the online MyDWETRA platform for assessing and predicting fire risk and providing early warning information to regional actors is a very good practice the country needs to build on. There is a need to build on this initiative to strengthen national capacity to predict and detect forest fires, by also encouraging active involvement of other key actors, such as the Ethiopian Meteorological Authority, EWCA and NDRMC.

EWCA's integrated forest fire management plan: EWCA's integrated forest management plan needs to be assessed for its possible adoption by actors such as OFWE, AFE and other sub-national actors.

Linking with regional and international partners: GFMC was instrumental in coordinating international assistance during the 2000 forest fires, and in coordinating training on firefighting skills, and soliciting logistics for building the country's capacity to suppress forest fires. Establishing linkages with international actors such as GFMC and USDA is essential for building capacity and benefiting from the transfer of state-of-the-art knowledge and technology in forest fire management.

Community-developed bylaws to control forest fires: Experience from SNNP Regional state was shared by workshop participants from Siltie Zone of SNNPRS on community initiated and adopted bylaws to prevent and control forest fires. As per the bylaw, community members prohibit human-induced fires and enforce appropriate measures and fines for those who violate agreed provisions. The use of community-based bylaws can be adopted widely in areas with similar circumstances.

Chapter 4: International experiences

In the process of establishing Ethiopia's forest fire management system, it is necessary to consider relevant international experiences, and to contextualize lessons learned from other countries to the Ethiopian context. This chapter provides a summary of relevant international experiences in the development of national forest fire management systems. Focus is on approach and considerations for designing the system, financing options, and opportunities for establishing linkages with partners for learning and knowledge transfer in establishing and running a national forest fire management system.

4.1 Establishing a national wildfire management system

It has become increasingly evident that fire management approaches focusing on fire suppression or exclusively on fire bans are becoming less sustainable as long-term fire management approaches (FAO, 2020). Global experiences point to a growing shift towards national forest fire management systems, from fire control to fire prevention and preparedness and near real time forest monitoring and prevention as the frequency and intensity of fire increases due to climate change and growing human activities (FAO, 2020). Thus, fire management across mosaic landscapes should aim at understanding the diversity of land uses and need to be planned at landscape level to create synergy among various land uses and management objectives. In traditional pastoral and agropastoral systems, for example, the use of prescribed fire is a necessity in maintaining the ecology of the system, conserving biodiversity and building adaptive capacities of communities. Fire management that disregards traditional land management knowledge would aggravate ecological degradation and vulnerability of communities.

4.2 Approaches

The approach to put in place a national forest fire management system that effectively predicts, prevents, and suppresses wildfires in Ethiopia is one that adequately considers the peculiarity of the diverse agroecological zones and socio-economic settings in the country and builds on relevant and successful experiences from within the country and elsewhere in the world. Accordingly, it is essential to be aware of contemporary thinking on holistic fire management. The approach should also engage local communities and use traditional knowledge that distinguishes beneficial and detrimental roles of fire in different natural and managed systems and employ the latest technologies in fire detection and suppression. Approaches to fire management should also place greater emphasis on addressing underlying causes, and seek long term, sustainable solutions.

A recommendable framework for fire management that systematically assesses, plans and manage fires is one characterized by the '5Rs', which are: review, risk reduction, readiness, response, and recovery. Review refers to a better understanding of fire issues and rationale for the identification of options. Risk reduction is about focusing on prevention, whereas readiness is about being better prepared to fight fires. Response involves timely and effective measures to reduce impacts on forests, landscapes, life and property, while recovery is about taking measures to restore fire-affected habitats and communities (FAO, undated). Such a framework would help in making the systems 'fire-smart' by integrating the sociocultural realities and ecological imperatives with technological innovations. Lessons from fire management experiences of fire prone countries point to the need to work towards establishing an integrated fire management system. This involves understanding benefits and risks of fire and developing integrated solutions to fire problems by implementing strategies that effectively manage both beneficial fires and detrimental fires (Myers, 2006). In integrating global experiences into a national forest fire management system, care should be taken to contextualise these experiences to fit social, ecological, economic, political and cultural peculiarities (see Box, below).

Box 3: Key aspects to consider in establishing a national wildfire management system

Key considerations in designing an integrated national forest fire management system are to:

- Make a clear distinction between fires that are ecologically, socially and economically beneficial, and those that are destructive for which fire management system is required.
- Be fully aware that fire management requires the bringing together of all sectors that use or depend on land (forestry, agriculture, livestock, mining, etc.).
- Consider the social, cultural, economic aspects of local communities while setting up a national fire management.

There are lessons from other countries like Indonesia and Namibia which can be used in the development of an integrated fire management system for Ethiopia (Goldammer and Abbgerger, 2000). The focus should be on fire prevention, while efforts thus far have been largely on detection and suppression. It is important to enhance capacity to prevent fires through identification of fire-prone areas and causes of ignition, to raise public awareness to prevent anthropogenic fires, to conduct pre-fire season monitoring, and to develop early warning system and fire detection. Fire management should not be treated as an emergency but a continual activity to reduce the risk of fire occurrence, improve detection, and ensure rapid and effective response and fire suppression to reduce impacts. In addition, integrated fire management must be community centred. Local communities are often implicated both as the causes of human induced fires and as major actors in suppressing fires. An integrated fire management system must ensure active engagement of communities, and should consider their needs, knowledge and capacities in fire management. There are valuable lessons and experiences from Uganda (Diemont and Wanders, 2022), Indonesia (MoA, 2000) and elsewhere that show how community based integrated fire management can be part of a national fire management system.

When planning an integrated national fire management system, countries are encouraged to consider the following guidelines adapted from Myers (2006) that take into account national, regional and local political, economic, social, ecological, and cultural realities. These are:

i. ***Understanding fire ecology across vegetation and land use types***: Understand the role of fire in natural vegetation dynamics and the beneficial or damaging impacts of fire management on vegetation ecosystem characteristics and functions.

ii. ***Documenting and promoting beneficial traditional fire use***: Knowledge underpinning traditional fire use needs to be properly documented, analyzed and promoted if they are found to be appropriate. Better understanding of the right ways of using fire as a recommended land management tool is critical to integrate it as part of the national forest fire management system.

iii. ***Community education to reduce anthropogenic fire incidences***: The success of a fire management system is dependent on awareness and participation of local communities. One strategy to minimize human caused fire incidences in high fire risk areas is to design and implement public awareness creation, training and capacity building.

iv. ***Revisiting the ban on fire***: The use of prescribed fire has been a traditional and integral part of land management practices, especially in the rangelands. However, legal restrictions on the use of fire imposed in past decades has resulted in ecological degradation. The fire management system should help in deregulating such provisions and create an enabling environment for use of recommended prescribed fires at the right time and place.

v. ***Building cost-effective fire prevention and response***: Develop and implement adequate and cost-effective detection, prediction and response tools and procedures to respond to unwanted fires and manage them in a timely manner to minimize impacts.

vi. ***Ensure local administration and community buy-in***: It is important to work towards engaging local authorities and communities in and around fire-prone areas and build partnership for establishing effective wildfire management system.

vii. ***Promote awareness that fire has beneficial roles***: It is recommended that policy makers be informed about ‘good’ and ‘bad’ fires. Beneficial fires are those in fire-dependent ecosystems that often follow a natural burning cycle and cause no long-term damage to ecosystems. This also includes well-planned and controlled agricultural fires that are used as part of land management practices.

viii. ***Education and training***: It is recommended that forestry agencies work with higher learning institutions to incorporate fire management into their curricula and training programs.

4.3 Financing options

Inadequate financial allocation for the forestry sector in general and for wildfire fire management in particular is a major constraint that should be addressed. Sustainable finance is essential to establish and operate a national forest management system that will work in a coordinated way to predict, detect and suppress forest fires, and rehabilitate burned areas. Thus, efforts to building Ethiopia’s wildfire management system should work towards exploring and securing sustainable financing options and identifying and prioritizing tasks that need to be implemented in the short, medium and long term.

4.3.1 Soliciting external support

Addressing the technical, technological and financial limitations that Ethiopia faces in building an effective national fire management system requires the country to better articulate its needs and solicit international support. This is better managed if a phased fund-raising and capacity development approach is followed that will be informed by clearly stated short-, medium-, and long-term objectives, and proposed implementation modalities. Bankable proposals need to be prepared and submitted to potential bilateral and multilateral donors and UN agencies that have been supporting the forestry sector in Ethiopia. The technical expertise of these partners and their knowledge and experience in navigating through the global finance landscape will improve the probability of securing funding. FAO for example has been engaged in forest fire programs at global, regional, and country levels. Partnering with these organizations will enhance Ethiopia's capacity to secure the much needed technical and financial support.

4.3.2 Cost-sharing with relevant sectors

Key land use sectors like forestry, agriculture and wildlife and tourism can work together as members of a yet to be-established national fire management coordination platform. Each sector has a stake in the protection of landscapes, forests and protected areas. Until a national fire management system is adequately and sustainably financed, these sectors could commit to an agreed financial contribution from their respective annual budgets. The pooled finance can then be used to implement jointly developed and agreed upon plans subject to review and approval by the platform. The initial focus is likely to be on fire prevention and awareness creation, as well as for building stronger multisectoral collaboration to facilitate the mobilization of additional resources and logistical support needed during firefighting campaigns. This option is recommended for the planning and implementation of short-term actions until financial mechanisms are put in place to fund activities in the medium and long term.

Chapter 5: Recommendations

This section outlines possible strategic level measures and actions to be considered in addressing the gaps and challenges identified earlier to build an integrated national forest fire management system.

5.1 Strategic measures and considerations

To contribute to filling gaps regarding policy and legal aspects, the following measures are proposed.

i. Develop a national land use policy and plan that facilitates the protection and sustainable use of Ethiopia's forest and rangelands resources.

ii. Develop a wildfire management system in consultation with concerned sectors (agriculture, livestock, wildlife, etc.) and all relevant actors at all levels to ensure buy-in and active involvement in its implementation. The fire management system be aligned with forest management and land use plans, and should clearly define its short-, medium- and long-term objectives, planned actions to achieve these objectives, as well as the roles of different stakeholder and coordination mechanisms.

iii. Develop forest management plans that have integrated and mainstreamed forest fire management, at least for the most fire-prone forests.

iv. Strengthen law enforcement to combat criminal fire ignitions by actively engaging relevant actors including the police, judiciary, local administrations, as well as communities nearby.

v. Given that some regional states, notably Gambella, Benishangul Gumuz and Amhara are affected by transboundary fires, put in place mechanisms to engage relevant authorities in neighbouring countries in detecting and controlling forest fires that national borders.

In addition, the following key undertakings are proposed to build and sustaining capacity and addressing institutional gaps as Ethiopia establishes a national fire management system.

i. **Developing a roadmap to building and maintaining capacity**. Building a national forest fire management system requires considerable resource and time. Given resource constraints and the urgency of fire threats, a practical approach is to prioritize short term and long-term activities. Thus, clearly articulated road map, milestones and implementation arrangements in the short, medium and long-term are needed in establishing and operationalising the system.

ii. **Balancing short-term and long-term fire management goals**. Targeted investments in forest fire prevention and early detection measures are more economical in terms of reducing fire suppression costs and damages due to fire. In the short-term, investing in fire prevention and detection activities is recommended for developing countries such as Ethiopia, while working in parallel to building national capacity in the long-term to prevent, quickly detect quickly, and efficiently suppress fire, and to rehabilitate impacted landscapes and livelihoods.

iii. **Integrating fire management into landscape-level planning and management.** Land users in rural Ethiopia have been managing landscapes for different uses and in different ways. In some land uses, use of fire is an integral part of the land management. Thus, effective fire management should be seen as part of the broader land management practice.

iv. **Engaging stakeholders and ensuring multistakeholder and multilevel resource governance.** As causes and impacts of fire transcend individual sectors, fire management calls for collaboration amongst all relevant sectors and actors. Moreover, different administrative levels need to work together for effective communication and efficient responses. Accordingly, while ensuring coordination at national level, the devolution of roles and responsibilities and increased support for local decision making is needed.

v. **Evidence-based planning and decision making**. Good understanding of fire ecology and its intricate relationships with biophysical variables and socioeconomic factors requires is necessary. Thus, empirical data is needed to better identify fire-sensitive and fire dependent ecosystems to clarify the beneficial roles of prescribed fires in land management. The merits and challenges of indigenous knowledge and traditional fire-use need to be critically assessed scientifically to inform the design of appropriate intervention options.

vi. **Recognition of indigenous knowledge and ensuring effective community engagement**. Local communities are often blamed for setting fires and must be fully engaged in the design and implementation of fire detection, reporting and control activities. Thus, community-based fire management needs to be integrated as an integral part of the national fire management system.

5.2 Building partnerships and international cooperation

Establishing linkages and building cooperation with regional, continental and international institutions is critical to support efforts of Ethiopia to put in place a national fire management system. Some of the benefits of such cooperation include accessing valuable data in fire prediction, obtaining knowledge and technology, as well as for training and capacity building in fire management. Below are some institutions with which establishing and building collaborations is recommended.

The Global Fire Monitoring Center (GFMC). As a global facility for vegetation fire monitoring, documentation and analysis, GFMC provides a portal for wildfire documentation, information and monitoring that is publicly accessible through the internet. The regularly updated national to global wildland fire products and services of the GFMC include the following.

- Liaison capabilities for providing assistance for rapid assessment and decision support in response to wildland fire emergencies under cooperative agreements with the Joint Environment Unit of the United Nations Environment Programme (UNEP).
- Early warning of fire danger and near-real time monitoring of fire events that includes the currently developing Global Wildland Fire Early Warning System and a global portal to existing national, regional and global fire weather and fire danger rating systems.

- Interpretation, synthesis and archiving of global fire information.
- Supporting countries and organizations in developing long term strategies or policies for wildland fire management, including community-based fire management approaches and advanced wildland fire management training for decision makers, especially in the prevention of and preparedness for wildfire disasters.

The Regional Eastern Africa Fire Monitoring Resource Center (REAFMRC). REAFMRC serves countries by generating, archiving, interpreting and disseminating scientific and technical information and satellite-derived near-real time and historic data on landscape fires. Its information is sought not only by forestry authorities but also by wildlife agencies. The mandate of REAFMRC includes the following.

- Organize consultations aimed at generating awareness and fostering cooperation among decision makers of all concerned sectors about the importance of fire management at landscape level, as a prerequisite for the implementation of national land management and environment policies.
- Support advanced landscape fire management training courses combined with field practice for professionals working in institutions with a role in landscape fire management or disaster risk reduction.
- Support national authorities in reaching out to civil society for their active participation in wildfire prevention and risk reduction, notably at local community level.

Food and Agriculture Organization of the United Nations (FAO). FAO has been facilitating the development of a comprehensive approach to integrated fire management through applying the 5Rs: review and analysis, risk reduction, readiness, response to fires, and recovery. The organization has a global mandate as a UN agency and is well placed to systematically engage from global to regional and national levels with fire management authorities, interested entities and institutions, as well as with multilateral actors (FAO, undated). Since 2020, FAO has been implementing a five-year program in 10 Asian and African countries to support the building of wildfire risk-reduction strategies and the operationalization of two regional fire management networks. The program helps countries to identify and scale up fire and land management systems that draw on practices of traditional fire knowledge and community-based fire management (FAO, 2020). FAO's technical capacity in forest fire management, forest resource assessment, disaster risk reduction, and its network of regional and country offices is ideally placed to connect, collaborate, advise on and facilitate integrated fire management where it is needed.

5.3 Establishing a national wildfire management system

In Ethiopia, there is no official information system that provides fire related data in general and on the fire hotspot areas in particular. It is recommended that fire information systems need to use the high-resolution Landsat and Sentinel images together with the MODIS based burned area maps in order to derive local level detailed fire related information. This study demonstrated the various types of questions that can be answered with the help of MODIS products. One major characteristic of fire in Ethiopia is its smaller area coverage than the pixel size of the MODIS products. Small fires represent an important under-represented fire type within a burned area dataset, especially in regions with substantial mixed land use/land cover dominated areas. In order to improve regional and global burned area mapping, the fire information system must focus on improving the mapping accuracy of the timing and spatial extent of these small fires. Methodologies need to be designed to better capture both large and small fires. This study validated the burned area map of selected sites using pre- and post-Landsat and Sentinel imageries. However, the applied validation approach was manual, which needs to be improved to reduce the intensive manual work.

The monthly analysis of the burned area must also consider the seasons of Ethiopia. In this study, the analysis year starts in October and ends in September. This allows the continuous analysis of the fire pattern. For instance, fire that started in December can last until the next year in February. Therefore, future studies on the temporal aspects of burned area analysis have to consider the continuity of the fire pattern in selecting temporal coverage of their studies.

5.4 Institutional arrangement and coordination of actors

As noted previously, the 2014 manual is the only available guideline on forest fire management in Ethiopia. The manual attempted to identify key stakeholders that should be involved from federal to local level in the form of task force, and the organization that should lead each. However, it is uncertain what measures have been taken to make these task forces operational.

Key considerations when putting in place appropriate institutional arrangements, are the identification of fire prone areas, engaging local administrations and communities in these areas, and strengthening the capacities of local sector offices, administrations and communities. Permanent firefighting brigades must be established, equipped with firefighting tools and vehicles, and finance for citizen mobilization as stipulated in the forest law, supported by fire detection and reporting systems.

Building on the structure suggested in the 2014 manual and based on the findings from KIIs and discussions with workshop participants, the following institutional arrangement is proposed. The structure takes into account current institutional arrangements and other realities. It involves a decentralized (Federal, Regional, Zonal and Woreda/district) institutional arrangement with defined roles and responsibilities at each level for improved alignment and coordination of fire prevention, detection and suppression activities.

Across levels, the coordination platform should be permanent that meets at least twice a year, to plan, coordinate and review implementation of activities related to predicting, preventing, timely detection and reporting, and suppression of fires, one well ahead of the annual fire season, and one right after. While each stakeholder has a role to play in fire prevention and control, specific roles related to reporting, responding, coordination and fire risk declaration need to be assigned to relevant stakeholders at each level. To this end, roles

Table 18: Proposed list of stakeholders for national level coordination task force

Institution	Mandate	Role
Ethiopia Forestry Development (EFD)	To support sustainable management of forest resources	Chair
National Disaster Risk Management Commission (NDRMC)	To coordinate and lead national disaster risk management	Vice-chair
Ministry of Agriculture (Natural Resource Directorate)	To execute NRM activities, and manage agriculture related fires	Secretary
Environmental Protection Authority	To reducing environmental impacts of wildfires	Member
Ethiopian Meteorology Agency	To forecast weather and provide early warning/alerts	Member
Ethiopian Space Science and Geospatial institution	To provide remote-sensing data to inform fire prediction and early warning system	Member
Ethiopia Biodiversity Institute (EBI)	To protect biodiversity resources of the country	Member
Ethiopian Wildlife Conservation Authority (EWCA)	To conserve and manage parks and wildlife	Member
Ministry of Culture and Tourism	Developing tourism and culture (e.g., protected areas)	Member
Ministry of Defence	To mobilize army and equipment during firefighting	Member
Federal police	To assist in firefighting and protecting people and property	Member
Ministry of Education	To train and mobilise University and high school students in firefighting	Member
Ministry of Peace	To enhance cooperation and reduce conflicts among communities	Member

and responsibilities are differentiated at different levels based on respective capacities and legal mandates. It should be noted that individual stakeholders at each administrative level are expected to execute their respective responsibilities on a day-to-day basis as part of their mandate. The task forces at each level shall focus on providing strategic guidance, ensuring effective coordination among actors when responding to fire incidences, facilitating resource and community mobilization, and overseeing performance and capacity building.

Task force at Federal level: At federal level, the task force shall

- Coordinate forest fire prevention, control and monitoring to ensure that national level fire-related tasks are well coordinated across sectors and provide guidance for monitoring performance.
- Communicate with and create strong linkages with regional platforms for preparedness, early fire detection and timely suppression and to ensure that responses to forest fire incidences are rapid, effective and efficient.

- Put in place procedures that ensure that fire incidences are rapidly reported to higher level offices – from sites/kebele to Districts, from Districts to Zones, from Zones to Regions, and from Regions to Federal level, so as to be able to swiftly respond and minimize impacts.
- Guide and support resource mobilization at all levels.
- Take measures to build and sustain capacity for fire prediction, detection, monitoring, and suppression, and for the restoration of burned areas.
- Support efforts to develop appropriate policy and legal frameworks by respective sectors and ensure that these are aligned and complementary.
- Put in place a mechanism to manage transboundary fires that require strategic direction and joint action with relevant authorities and communities in neighbouring countries.
- Build external partnerships with and mobilize assistance from relevant regional and international forest-fire related bodies (e.g., GFMC), and lay the foundations for coordinating efforts to solicit and use international assistance.

Task force at regional level: The task force at sub-national or regional states level shall:

- Coordinate forest fire prevention, control and monitoring within the respective Regions, and that regional responses to fire incidences are rapid, effective and efficient,
- Ensure that regional level fire-related tasks are well coordinated across sectors and provide guidance for monitoring performance of actors at Regional and lower levels.
- Create strong linkage with national and district level platforms through effective communications for preparedness, early fire detection and suppression, and inform the Federal Government if fires are at risk of becoming beyond control.
- Guide and support resource mobilization at Regional and lower levels, and ensure complementarity with national and local efforts, with no gaps or overlaps.
- Ensure that Regional legal and institutional frameworks are aligned with national frameworks, while being relevant to contexts and specificities of the Region, and that they are duly implemented.
- Coordinate, guide and lead awareness raising and preparedness in the respective Regions.
- Provide guidance on cross-regional state fire management activities and coordinate relevant regional sectors in their engagement in fighting cross-regional wildfires.
- Coordinate and guide communications with zonal and district level coordination platforms.
- See to it that relevant laws are enforced. Strong law enforcement at sub-national level is important for protecting forests and other natural resources from fires. Ensuring that criminals are dully penalised discourage criminal activities in the respective Regions.

Task force at Zonal level: The tasks are largely similar to the regional task force but will be focused on Woredas in their respective Zones. Tasks to be implemented will be delegated by the regional task force, which will work with and support woreda task forces.

Table 19: Proposed list of stakeholders for regional level coordination task forces

Institutions	Mandate	Role
Regional office in charge of forestry	To develop forest sector in the Region	Chair
Regional EFD Office	To implement duties and responsibilities of EFD	Co-chair
Bureau of Agriculture	To manage natural resources	Secretary
The Office of Regional Administration/ security	To provide political and security support	Member
Regional Environmental Protection Authority	Responsible for sub-national forest and environmental protection activities	Member
Regional DRM bureaus	Responsible in coordinating sub-national level DRM	Member
Regional Police	To ensure public safety	Member
Regional Justice Bureau	Responsible for law enforcement	Member
Forest enterprises (where available)	Mandated to manage forests under their Jurisdiction	Member
NGOs/CSOs working on natural resources (representative)	Engage in forestry/conservation/NRM activities	Member

Table 20: Proposed list of stakeholders for zonal level coordination task force

Institution	Mandate	Role
Zonal Administration Office/Security	To provide political and security support	
Zonal Agriculture Office	To implement NRM development and protection activities	Chair
Zonal Forestry / Environmental Protection Office	Mandated to manage forest resources	Co-Chair
Forest Enterprise Zonal branches	Mandated to manage forests under their jurisdiction	Secretary
Zonal Justice Office	Mandated to ensure law enforcement	Member
NGOs working on natural resources	Engage in forestry/conservation/NRM activities	Member

Task force at Woreda/district level: Constitutionally, districts are empowered to make decisions including budget allocations to sectors and activities in their woreda. Thus, having a strong task force at woreda level is critical for operationalising fire management system in Ethiopia. The following are proposed tasks of the Woreda task force.

- Coordination and monitoring of fire prevention and control activities across sectors and kebeles in the woreda.
- Identification of fire prone Kebeles in the Woreda and putting in place early detection and rapid reporting mechanisms that Kebeles and community members shall follow.

Table 21: Proposed list of stakeholders for woreda level coordination task forces

Institution	Mandate	Role
Woreda Administration Office	Provide political and security support at woreda level	Chair
Woreda Office in charge of forestry	Promote forest development	Secretary
Woreda Agriculture Office	Execute NRM activities	Member
Woreda Justice Office	Ensure law enforcement	Member
Kebele Administrators	Provide support for kebele level coordination	Member
Kebele Agriculture/ Forestry Office	Responsible for NRM activities	Member
Representatives of community-based fire management units (1 per kebele)	Mobilise and engage communities in fire management	Member

- Ensure that appropriate fire prevention infrastructure (fire breaks, roads, fire towers, etc.) are established across fire-prone areas within the Woreda and that appropriate pre-fire season preparedness work is accomplished in fire prone Kebeles.
- Support the establishment of community-based fire management units across kebeles and define modalities of operation.
- Put in place mechanism to mobilize communities, law enforcement agents, students and citizens for firefighting campaigns, and provide logistical and financial support for controlling wildfires
- Ensure that laws are enforced to reduce criminal fire ignitions.
- Put in place effective communication system with Kebeles regarding fire management so that actors play their respective roles in fire detection, reporting and control.

5.5 Building and maintaining capacity at all levels

Assessing the organizational capacity of relevant actors – from communities and local administration to national sectoral ministries – is the first step to determine capacity building activities. A review of reports and responses from key informants and workshop participants reveal that there is a huge capacity gap at all levels, and that addressing these gaps will require time and finance. The following actions are proposed to address gaps related to data, skills and logistics.

i. Identify data related gaps (fire statistics, fire detection, reporting, monitoring, efficient communication, post-fire assessments, etc.) and options to bridging gaps

ii. Identify knowledge and skill gaps of experts in predicting, monitoring, detecting, reporting and suppressing fires, and design and conduct tailored training to build capacity. Training should also involve local administrators and communities.

iii. Identify and address technological and logistical gaps for effective fire management at all levels. In particular, identify what types of equipment are needed at what levels so as to build an efficient community-based fire management system. As building technological and logistical capacity require major investment, short term needs must first be fulfilled, followed by medium- and long-term plans as part of building a comprehensive national fire management system.

iv. Develop sustainable financing system. Financial constraints continue to be the major limiting factors in establishing and operationalizing a national fire management system. Efforts should begin with assessing financing options from domestic and international sources for supporting fire prevention and suppression. The federal government and fire Regions and districts could begin allocating budget as part of their annual budget.

References

Abate T. 2016. Indigenous ecological knowledge and pastoralist perception on rangeland management and degradation in Guji Zone of South Ethiopia. *Journal of Sustainable Development* 15(1): 192-218.

Abdu NH and Robinson LW. 2017. Community-based rangeland management in Dirre rangeland unit: Taking Successes in Land Restoration to scale project. *ILRI Project Report*. ILRI, Nairobi, Kenya.

Addis Fortune. 2019. Fire re-ignites and blazes in Siemen Mountains. *Addis Fortune 20(989)*, 13 April.

AfCo. 2022. Forest fire management in the tropics. Asian Forest Cooperation Organization. 32p. https://afocosec.org/wp-content/uploads/2022/04/KN2022-007-Forest-Fire-Management-in-the-Tropics-220425_compressed.pdf

Angassa A. 2007. The dynamics of savanna ecosystems and management in Borana, southern Ethiopia. PhD thesis, Norwegian University of Life Sciences (UMB), Ås, Norway. 183pp.

Angassa A and Oba G. 2008. Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on the rangelands of Borana, Southern Ethiopia. *Human Ecology* 36(2): 201-215.

Anonymous. 1988. National Atlas of Ethiopia. Ethiopian Mapping Authority, Addis Ababa.

Anonymous. 2022. Review of forest fires and government responses in Ethiopia, Addis Ababa, 29pp.

Archibald S, Lehmann CER, Gömez-Dans JL and Bradstock RA. 2013. Defining pyromes and global syndromes of fire regimes. *Proceedings of the National Academy of Sciences of the United States of America*, 110: 6442-6447.

Bailey RG. 2005. Identifying ecoregion boundaries. *Environmental Conservation* 34(1): S14-S26.

Bekele M and Mengesha B. 2001. Fire situation in Ethiopia. *International Forest Fire News* 25: 7–11.

Belayneh A, Yohannes T and Worku A. 2013. Recurrent and extensive forest fire incidence in the Bale Mountains National Park (BMNP), Ethiopia: extent, cause and consequences. *International Journal of Environmental Sciences* 2(1): 29-39.

Bollig M and Schulte A. 1999. Environmental change and pastoral perceptions: degradation and indigenous knowledge in two African pastoral communities. *Human Ecology* 27: 493–514.

Bowman DMJS, Balch J, Artaxo P, Bond W.J, Cochrane MA, D'Antonio CM et al. 2011. The human dimension of fire regimes on Earth: the human dimension of fire regimes on Earth. *Journal of Biogeography* 38: 2223–2236.

Bowman, DMJS., Balch, JK., Artaxo, P., Bond, WJ., Carlson, JM., Cochrane, MA., D'Antonio, CM., DeFries, RS., Doyle, JC., Harrison, SP., Johnston, FH., Keeley, JE., Krawchuk, MA., Kull, CA., Martson, B., Moritz, MA., Prentice, C., Roos, CI., Scott, AC., Swetnam, TW., van der Werf, GR. And Pyne, SJ. (2009). Fire in the earth system: review. *Science* 324(5926): 481-484.

Butz RJ. 2009. Traditional fire management: historical fire regimes and land use change in pastoral East Africa. *International Journal of Wildland Fire* 18: 442–450.

Casals P, Valor T, Besalú A and Molina-Terrén D. 2016. Understory fuel load and structure eight to nine years after prescribed burning in Mediterranean pine forests. *Forest Ecology and Management* 362: 156–168.

Coppock DL, Gebru G, Desta S, Gizachew L, Amosha D and Taffa F. 2007. Stakeholder alliance facilitates re-introduction of prescribed fire on the Borana plateau of southern Ethiopia. *ENVS Faculty Publication, Paper* 209. 7pp.

Dalle G, Isselstein J and Maass BL. 2005. Indigenous ecological knowledge of Borana pastoralists in southern Ethiopia and current challenges. *International Journal of Sustainable Development and World Ecology*, 12: 1–18.

Diemont R and Wanders T. 2022. A community-based approach to wildfire prevention in Ghana. pp147-153, In: Pasiecznik N and Goldammer JG (eds.), Towards fire-smart landscapes. *Tropical Forest Issues* 61. Tropenbos International, Ede, the Netherlands. 191 pp.

D'Odorico P, Laio F, Porporato A, Ridolfi L and Barbier N. 2007. Noise-induced vegetation patterns in fire-prone savannas. *Journal of Geophysical Research* 112: G2.

D'Odorico P, Laio F and Ridolfi L. 2006. A probabilistic analysis of fire-induced tree-grass coexistence in Savannas. *American Naturalist* 167: E79–87.

Doerr SH and Santın C. 2016. Global trends in wildfire and its impacts: perceptions versus realities in a changing world. *Philosophical Transactions of the Royal Society* B 371: 20150345.

Ebro A and Mengistu A. 2015. State of rangeland condition and trends in Ethiopia. pp 3-25, In: Yaini A, Assefa G and Gizachew L (eds.). Proceedings of Pasture and Rangeland Research and Development in Ethiopia. 169pp.

EFCCC. 2019. Forest fire management in Ethiopia, experiences and challenges. In: Fire Trends in Ethiopia in the Context of REDD+ and FLR Investments, Addis Ababa, Ethiopia. https://www.slideshare.net/CIFOR/forest-fire-management-in-ethiopia-experiences-and-challenges

Ericksson I, Teketay D and Granstrom A. 2003. Response of plant communities to fire in an Acacia woodland and dry Afromontane Forest, southern Ethiopia. *Forest Ecology and Management* 177: 39-50.

Fana Broadcasting Corporation (FBC). 2022. Ethiopia plants 25 billion seedlings in four years surpassing the set ceiling: PM Abiy Ahmed. Fana Broadcasting Corporation, 15 August, https://www.fanabc.com/english/ethiopia-plants-25-billion-seedlings-in-four-years-surpassing-the-set-ceiling-pm-abiy-ahmed/

FAO. 2012. State of the world forests. FAO, Rome, Italy. www.fao.org/3/i3010e/i3010e00.htm.

FAO. 2020. Fire-smart Forest management: Strengthening knowledge to combat wildfires and boost wildfire resilience. 2pp. https://www.fao.org/3/ca7957en/CA7957EN.pdf

FAO. undated. FAO strategy on forest fire management. https://www.fao.org/forestry/49772-0e64392e1b16124967bab33b6cbd84417.pdf

FDRE. 2011. Ethiopia's Climate-Resilient Green Economy: Green Economy Strategy. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

FDRE. 2013. National Policy and Strategy on Disaster Risk Management (DRM). Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia. https://www.refworld.org/pdfid/5a2689ea4.pdf

FDRE. 2015. Climate Resilience Strategy: Agriculture and Forestry, Ethiopia's Climate Resilient Green Economy. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia. 70pp.

FDRE. 2017. REDD+ Investment Program (2017–2020). Ministry of Environment, Forest and Climate Change (MEFCC), Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

FDRE. 2018. Forest Development, Conservation and Utilization Proclamation. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

FDRE. 2019. Ethiopia's National Adaptation Plan: Ethiopia's Climate Resilient Green Economy. Federal Democratic Republic of Ethiopia Addis Ababa, Ethiopia. 162pp.

FDRE. 2021. Ethiopia's Updated Nationally Determined Contribution. Environment, Forest and Climate Change Commission (EFCCC), Federal Democratic Republic of Ethiopia Addis Ababa, Ethiopia.

Findlay N, Manson A, Cromsigt JPGM, Gordijn P, Nixon C, Rietkerk M, Thibaud G, Wassen MJ and te Beest M. 2022. Long-term frequent fires do not decrease topsoil carbon and nitrogen in an Afromontane grassland. *African Journal of Range and Forage Scienc*e, DOI: 10.2989/10220119.2021.2016966.

Friis I, Demissew S, Van Breugel P. 2010. *Atlas of the potential vegetation of Ethiopia*. Biologiske Skrifter (BiolSkrDan VidSelsk) 58:307.

Fule PZ. 2002. Comparing ecological restoration alternatives: Grand Canyon, Arizona. *Forestry Ecology and Management* 170: 19–41.

Gebru G, Desta S, Coppock DL, Gizachew L, Amosha D and Taffa F. 2007. Stakeholder alliance facilitates re-introduction of prescribed fire on the Borana plateau of southern Ethiopia. *Research Brief* 07-02.-PARIMA Global Livestock Collaborative Research Support Program. 7pp.

Geiger EL, Gotsch SG, Damasco G, Haridasan M, Franco AC and Hoffmann WA. 2011. Distinct roles of savanna and forest tree species in regeneration under fire suppression in a Brazilian savanna. *Journal of Vegetation Science* 22: 312–321.

Getahun M. 2009. Postfire influence on erica shrubland within the Afroalpine vegetation: A case study in south of the Bale Mountains National Park, southeast Ethiopia. MSc thesis, Addis Ababa University, Ethiopia. 108pp.

Gil-Romera G, Carole A, Benitos BM, Bittner L, Johansson MU, Grady DA et al. 2019. Long-term fire resilience of the Ericaceous Belt, Bale Mountains, Ethiopia. *Biological Letters* 15: 20190357.

Global Disaster Alert and Cooperation System (GDACS) https://www.gdacs.org/Wildfires/report.aspx?eventtype=WF&eventid=1005253&episodeid=4,

Global Fire Monitoring Center (GFMC). 2000. Ethiopia: Fire emergency between February and April 2000. Global Forest Management Center, *International Forest Fire News* 22. 10pp.

GFMC. 2019. Israeli firefighters arrive to contain Ethiopia's wildfire. Global Forest Management Center. gfmc.online/media/2019/04-2019/news_20190414_il.html

GFMC, undated, About the GFMC: Background information. Global Fire Monitoring Center. https://gfmc.oline/intro/about1.html

Global Wildfire Information System (GWIS) Database https://gwis.jrc.ec.europa.eu/apps/country.profile/chartsba

Godgil M, Rao PRS, Utgarsh G, Pramod P and Chhatre A. 2000. New meanings for old knowledge: the peoples biodiversity registers program. *Ecological Applications* 10: 1307–1317.

Goldammer JG and Abbgerger H. 2000. The integrated forest fire management concept: lessons learnt from Indonesia and opportunities to transfer the concept to Ethiopia. In: Proceedings of Round Table Conference on Integrated Forest Fire Management in Ethiopia, 19-20 September 2000, Ministry of Agriculture, Addis Ababa, Ethiopia.

Gudesho G and Woldu Z. 2021. Land use, land cover changes and their driving force in Wombera District, Benshangul Gumuz Regional State, Ethiopia. *International Journal of Environmental Protection and Policy* 9(5): 110-122.

Hoffmann WA, Orthen B and do Nascimento PKV. 2003. Comparative fire ecology of tropical savanna and forest trees. *Functional Ecology* 17: 720–726.

IUFRO. 2018. Global fire challenges in a warming world. In: Robinne FN, Burns J, Kant P, de Groot B, Flannigan MD, Kleine M and Wotton DM (eds.). *Occasional Paper* No. 32. International Union of Forest Research Organizations, Vienna, Austria.

Johansson MU, Granstorm A and Malmer A. 2013. Traditional fire management in the Ethiopian highlands: what would happen if it ends? Forest Facts, Swedish Agricultural University (SLU), Uppsala, Sweden. 5pp.

Johansson MU, Senay SD, Creathorn E, Kassa H and Hylander K. 2019. Change in heathland fire sizes inside vs. outside the Bale Mountains National Park, Ethiopia, over 50 years of fire-exclusion policy: lessons for REDD+. *Ecology and Society* 24(4): 26.

Jolly WM, Cochrane MA, Freeborn PH, Holden ZA, Brown TJ, Williamson GJ et al. 2015. Climate-induced Variations in Global Wildfire Danger from 1979 to 2013. *Nature Communications* 6: 7537.

Kayijamahe E and Otieno V. 2020. Wildfires in eastern Africa — Will climate change increase the intensity of wildfires? Contributions by ICPAC Climate Change Technical Working Group.

LaMalfa EM, Gebru G, Amosha D and Coppock DL. 2008. Guidelines on the application of prescribed fire in the Borana rangelands of Ethiopia. Addis Ababa, Ethiopia.

Laris P. 2002. Burning the seasonal mosaic: preventative burning strategies in the wooded savannah of southern Mali. *Human Ecology* 30: 155–186.

Lavorel S, Flannigan MD, Lambin EF and Scholes MC. 2006. Vulnerability of land systems to fire: interactions among humans, climate, the atmosphere, and ecosystems. *Mitigation and Adaptation Strategies for Global Change* 12: 33–53.

Lemessa D and Perault M. 2001. Forest fires in Ethiopia: Reflections on socio-economic and environmental effects of the fires in 2000. Assessment Study: June - September 2001. ReliefWeb.

Liu Z, Ballantyne AP and Cooper LA. 2019. Biophysical feedback of global forest fires on surface temperature. *Nature Communication* 10: 214–219.

Mapinduzi AL, Oba G, Weladji RB and Colman JE. 2003. Use of indigenous ecological knowledge of the Maasai pastoralists for assessing rangeland biodiversity in Tanzania. *African Journal of Ecology* 41: 329–336.

Mbow C, Nielsen TT and Rasmussen K. 2000. Savanna fires in east-central Senegal: distribution patterns, resource management, and perception. *Human Ecology* 28: 561–583.

MEF. 2014. የደን ቃጠሎን ለመከላከልና ለመቆጣጠር የተዘጋጀ ማኑዋል, MEF (ታህሳስ 2007 E.C.) (Manual for fire prevention and control), Ministry of Environment and Forest, Addis Ababa, Ethiopia.

MEFCC. 2018a. Ethiopia's national REDD+ strategy. National REDD+ Secretariat, Ministry of Environment, Forest and Climate Change, Addis Ababa, Ethiopia.

MEFCC. 2018b. National Forest Sector Development Program, Volume II: Program Pillars, Action Areas and Targets. Ministry of Environment, Forest and Climate Change, Addis Ababa, Ethiopia.

Meyn A, White PS, Buhk C and Jentsch A. 2007. Environmental drivers of large, infrequent wildfires: the emerging conceptual model. Progress in Physical Geography: *Earth and Environment* 31: 287–312.

MoA. 2000. Proceedings of the round table conference on integrated forest fire management in Ethiopia, 19-20 September 2000, Ministry of Agriculture, Addis Ababa, Ethiopia, in collaboration with GTZ and GFMC.

Moritz MA, Batllori E, Bradstock RA, Gill AM, Handmer J, Hessburg PF et al. 2014. Learning to coexist with wildfire. *Nature* 515: 58–66.

Myers RL. 2006. Living with fire—Sustaining ecosystems & livelihoods through integrated fire management. The Nature Conservancy, Global Fire Initiative. 36pp.

Nelson DM, Verschuren D, Urban MA and Hu FS. 2012. Long-term variability and rainfall control of savanna fire regimes in equatorial East Africa. *Global Change Biology* 18: 3160–3170.

Pavanello S and Levine S. 2011. Rules of the range natural resources management in Kenya–Ethiopia border areas. Humanitarian Policy Group (HPG) Working Paper, London, UK. 36pp.

Rogers BM, Balch JK, Goetz SC, Lehmann CER and Turetsky M. 2020. Focus on changing fire regimes: interactions with climate, ecosystems, and society. *Environmental Research Letters* 15: 030201.

Sá ACL, Pereira JMC, Charlton ME, Mota B, Barbosa PM and Fotheringham AS. 2011. The pyrogeography of sub-Saharan Africa: a study of the spatial non-stationarity of fire–environment relationships using GWR. *Journal of Geographical Systems* 13: 227–248.

Secretariat of the CBD. 2001. Impacts of human-caused fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes. CBD Technical Series 5. Secretariat of the Convention on Biological Diversity, Montreal, Canada. 42pp.

Solomon TB, Snyman HA and Smit GN. 2007. Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. Journal of Environmental Management 82(4): 481-494.

Teketay D. 2000. Vegetation types and forest fire management in Ethiopia. pp 1-35, In: Proceedings of the Round Table Conference on Integrated Forest Fire Management in Ethiopia. Ministry of Agriculture (MoA), Addis Ababa, Ethiopia.

Temesgen D and Gebru G. 2015. Policy and institutional gaps in the protection and management of the rangelands in Ethiopia. pp 145-166, In: Yaini A, Assefa G and Gizachew L (eds.), Proceedings of Pasture and Rangeland Research and Development in Ethiopia. 169pp.

Terefe B and Kim D-G. 2020. Shifting cultivation maintains but its conversion to mono-cropping decreases soil carbon and nitrogen stocks compared to natural forest in Western Ethiopia. Plant Soil 453: 105–117.

TerrAfrica (undated). Africa The Fire Continent. 44pp.

Teshome E and Glatzel G. 2018. The effect of wildfire on *Erica arborea* L. (Ericaceae) in Simien Mountains National Park, northwest Ethiopia. *Proceedings of the International Academy of Ecology and Environmental Sciences* 8(3): 151-161.

The Nature Conservancy. 2004. Fire, ecosystems and people. Global Fire Initiative, Tallahassee, USA. 9pp.

Tilahun K, Nigatu L and Mengistu S. 2015. Traditional rangeland management and utilization practices of Nuer pastoralists in Gambella, Ethiopia. *The Journal of Agriculture and Natural Resources Sciences* 2(4): 649-660.

Tilahun M, Angassa A, Abebe A and Mengistu A. 2016. Perception and attitude of pastoralists on the use and conservation of rangeland resources in Afar Region, Ethiopia. *Ecological Processes* 5: 18.

Trollope WSW. 2011. Personal perspectives on commercial versus communal African fire paradigms when using fire to manage rangelands for domestic livestock and wildlife in southern and east African ecosystems. *Fire Ecology* 7(1): 57-73.

Tyukavina A, Potapov P, Hansen MC, Pickens AH, Stehman SV, Turubanova S et al. 2022. Global trends of forest loss due to fire from 2001 to 2019. *Frontiers in Remote Sensing* 3: 825190.

USFS. 2011. International Programs Pastoral Livelihoods Initiative -II. Technical assistance trip to Ethiopia, February-March 2011. US Forest Service. 28pp.

USFS. 2010. Technical assistance trip, Federal Democratic Republic of Ethiopia. In: Support to USAID-Ethiopia for Assistance in Rangeland Management, Pastoralist Livelihoods Initiative, Prescribed Fire Workshop Mission Report, 15 September – 2 October 2009. US Forest Service. 22pp.

van Breugel P, Friis I, Sebsebe D, Lillesø JPB and Kindt R. 2016. Current and future fire regimes and their influence on natural vegetation in Ethiopia. *Ecosystems* 19: 369–386.

Walker XJ, Baltzer JL, Cumming SG, Day NJ, Ebert C, Goetz S et al. 2019. Increasing wildfires threaten historic carbon sink of boreal forest soils. *Nature* 572: 520–523.

Worku, A. and Zewdie, W. 2008. The 2008 Fire incidence in Asebot forest: cause, impact and its implication for sustainable management of the ever-fragmented dry Afromontane forests in Ethiopia. Ethiopian Institute of Agricultural Research, Forestry Research Center. 31pp

Worldwide Fund for Nature (WWF). 2020. Fire, forests and the future: A crisis raging out of control? Worldwide Fund for Nature, Boston Consulting Group. 21pp.

Xu X, Jia G, Zhang X, Riley WJ and Xue Y. 2020. Climate regime shift and forest loss amplify fire in Amazonian Forests. *Global Change Biology* 26: 5874–5885.

Zerga B, Workineh B, Teketay D and Woldetsadik M. 2018. Rangeland degradation and rehabilitation efforts in the Somali National Regional State, eastern Ethiopia: A review. *International Journal of Innovative Research and Development* 7(5): 84-100.

Annexes

Annex 1. Questionnaire used to gather data from key informants and experts

Part I: Forest fires response experiences and impacts

Part I: Forest fires response experiences and impacts

1.1 How much of a concern are forest fires in your regional state? How frequent are forest fires in your regional state? (seasonal/annual; occasional/rare).

1.2 What percent of forest fires in your regional state would you say are caused by natural versus human sources? (Please enter a whole number for each, rounding to the nearest percent. Natural sources might include lightning, friction, etc. Human sources include any accidental, negligent, deliberate, or other use of fire.)

1.3 In your view, what are the 6 most common causes of forest fires in your regional state? Please rank in order, beginning with the top cause.

1.4 Is traditional forest fire management and/or prescribed fire practiced in your regional state? If so, what are they? Are they considered legal or illegal?

1.5 How important is the local community in managing forest fires? What roles do they play?

1.6 How do you evaluate the impact of recurrent forest fires on forest resources at regional/national level?

1.7 Based on past forest fire incidences, what kind of response mechanism have been developed or put in place in your *regional state*? (Actions taken, coordination mechanism, response effectiveness, etc.). How are these responses financed, if any?

1.8 What is the role of your organization in fire prevention, suppression/management at *regional/national* level?

1.9 Are there on-going initiatives or plans for improved forest fires management in your regional state?

1.10 Are laws related to forest fire enforced to the extent required in your Region? If not, why?

1.11 What are the protocols/procedures used to report, suppress forest fires in your region?

1.12 How are resources mobilized, if any, to support forest firefighting efforts when fires break?

1.13 How are communities and others such as the military mobilized to support firefighting efforts?

1.14 Is there clarity as to which organization is mandated to declare forest fires in your region?

1.15 Is there clarity as to which organization is mandated to initiate responses to fight forest fires? (i.e., forestry/agriculture bureau/office, or disaster management agency)?

Part II: Challenges in fire prevention and management (capacity, institutional, policy and legal)

2.1 How do you evaluate the capacity (logistics/infrastructure, skill, etc.) for forest fires prevention and management in your *region/institution*?

2.2 What are the key capacity gaps in your *region/institution*?

2.3 Is there operational institutional arrangement for stakeholder mobilization and coordination in forest fires suppression/prevention/management at *regional/national* level?

2.4 What enabling environment (policy/legal frameworks) is/are available/operational to support forest fire prevention/management in your *regional state/nationally*?

2.5 What legal restrictions exist for burning agricultural lands adjoining forests in your *regional state*?

Annex 2. Supplementary data

The following tables are available as supplementary data and can be accessed from PENHA Ethiopia.

- Sample of burned area data (ha) by district, year, month, and land cover
- Sample of burned area data (ha) by basin, year, month, and land cover
- Burned area in ha by district, year, land cover, and month
- Monthly burned area comparison by basin, year, land cover, and month

The following maps/charts are available as supplementary data and can be accessed from PENHA Ethiopia.

- MODIS based Land cover of Ethiopia for each year from 2001 to 2021
- Ethiopia level spatial distribution of fire occurrence independent of the land cover types
- Ethiopia level spatial distribution of fire occurrence in forest dominated areas
- Ethiopia level spatial distribution of fire occurrence in shrub / herbaceous vegetation dominated areas
- Ethiopia level spatial distribution of fire occurrence in crop land
- Fire host spot area across Ethiopia: class 1 (10 - 15 years of fire occurrence), class 2 (over 15 years of fire occurrence)
- Fire host spot area across Ethiopia: class 1 (10 - 15 years of fire occurrence), class 2 (over 15 years of fire occurrence) independent of the land cover
- Fire host spot area across Ethiopia: class 1 (10 - 15 years of fire occurrence), class 2 (over 15 years of fire occurrence) and the district administrations
- Fire hotspots and the neighbouring countries of Ethiopia: blue lines represent the districts with large areas of fire hotspots
- Ethiopia level spatial distribution of fire occurrence independent of the land cover types and the district administrations
- Spatial distribution of fire occurrence for each district with high burned area occurrences
- Fire- and non- fire months by year for each district with high burned area occurrences
- Monthly boxplot of the burned areas for each district with high burned area occurrences
- Fire- and non- fire months by year for each basin
- Monthly boxplot of the burned areas for each basin

Annex 3. List of acronyms and abbreviations

A/R	afforestation/reforestation
AFE	Amhara Forest Enterprise
CBiFM	Community-based integrated Fire Management
CRGE	Climate Resilient Green Economy
CRS	Climate Resilience Strategy
DRMC	Disaster Risk Management Commission
EFCCC	Environment, Forest and Climate Change Commission
EFD	Ethiopian Forestry Development
EWCA	Ethiopia Wildlife Conservation Authority
FAO	Food and Agricultural Organization of the United Nations
FDRE	Federal Democratic Republic of Ethiopia
GEE	Google Earth Engine
GFMC	Global Fire Management Center
GFW	Global Forest Watch
GHG	greenhouse gases
GLI	Green Legacy Initiative
GWIS	Global Wildfire Information System
IFM	integrated fire management
KII	key informant interview
LUCF	land use change and forestry
MCD64A1	Modis Burned Area Monthly Global 500 m
MEFCC	Ministry of Environment, Forest and Climate Change
MoA	Ministry of Agriculture
MODIS	Moderate Resolution Imaging Spectroradiometer
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NFSDP	National Forest Sector Development Program
OFWE	Oromia Forest and Wildlife Enterprise
PENHA	Pastoral and Environmental Network in the Horn of Africa
PFM	Participatory Forest Management
R	Programming language
REAFMRC	Regional Eastern Africa Fire Monitoring Resource Center
REDD+	Reducing Emissions from Deforestation and Forest Degradation
USAID	United States Agency for International Development
USFS	United States Forest Service

Ethiopian Forestry Development

PENHA
PASTORAL & ENVIRONMENTAL NETWORK IN THE HORN OF AFRICA

CIFOR

World Agroforestry

TROPENBOS INTERNATIONAL