Heat, Harm, and Hope: Ghana's Savanna Ecosystem Services in a Fiery Climate

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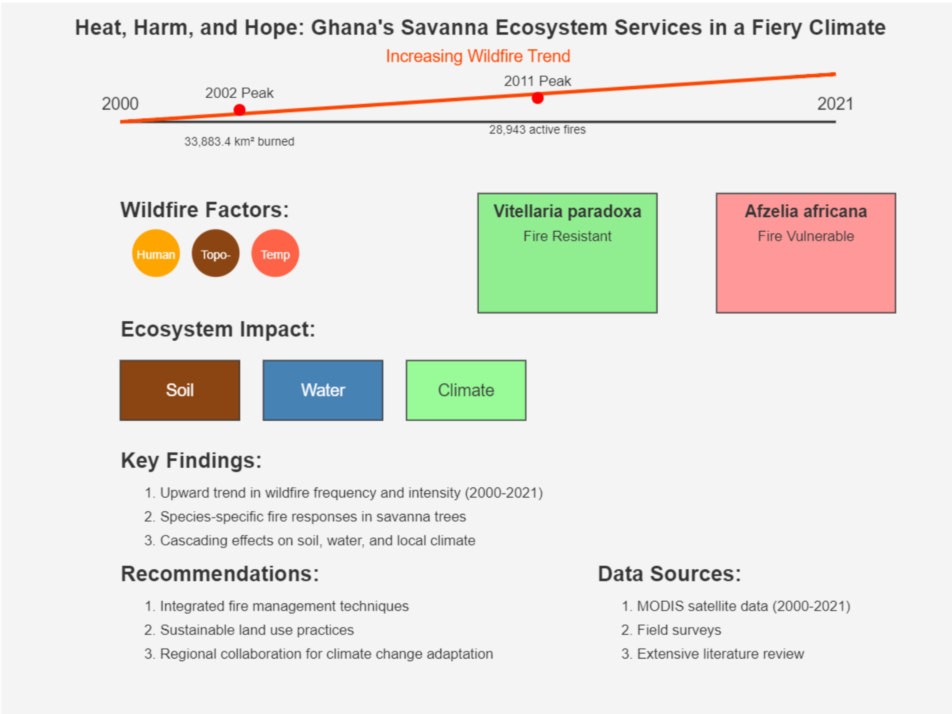
Graphical Abstract



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Abstract

This study investigates the link between wildfires and ecosystem services within Ghana's northern savanna through an integrative approach combining satellite data analysis, field surveys, and an extensive literature review. Analysis of MODIS data from 2000 to 2021 reveals an upward trend in both the frequency and intensity of wildfires, with notable peaks in 2011 (28,943 active fires) and 2002 (33,883.4 km^2 of burned area). Key factors influencing wildfire dynamics were identified as proximity to human settlements, topographical features, and maximum temperature. Field surveys highlighted species-specific responses, with Vitellaria paradoxa demonstrating significant fire resistance, in contrast to the vulnerability observed in Afzelia africana. The research further elucidates the cascading effects of wildfires on soil properties, water quality, and local climate regulation. The study emphasizes the need for integrated fire management techniques that prioritize prevention and mitigation above suppression. Addressing the wildfire issue requires sustainable land use practices, climate change adaptation, and regional collaboration.

Keywords: Wildfires, Ecosystem services, Savanna, Ghana, Climate change, Conservation

1 Introduction

The northern savanna of Ghana is a significant ecosystem consisting of expansive grassland with scattered trees and plays a crucial role in providing various services that are needed for both human well-being and environmental sustainability (Paterson et al., 1998). The savanna's impact on local economies, through activities including agriculture, cattle grazing, and the extraction of non-timber forest products, highlights its significance to Ghana's socio-economic structure. The ecosystem services are facing a greater risk due to the rising occurrence and severity of wildfires, which are worsened by climate change and changing land-use patterns. Given the increasing pace of climate change and the expanding scope of human activities, it is imperative to comprehend the intricate relationships between wildfires and ecosystem services to develop efficient strategies for managing and conserving these ecosystems (Hurteau et al., 2014). Ghana has seen numerous problems in recent years (2021-2023), including the ongoing recovery from the COVID-19 pandemic and a rise in wildfire occurrences in the northern savanna region. Although not approaching the extraordinary magnitudes observed in Australia (2019-2020) or the United States (2020), Ghana's wildfire situation has nonetheless raised concerns. Over the past two decades, the frequency and intensity of wildfires in the northern savanna have increased significantly, posing substantial risks to biodiversity, ecosystem functions, and human livelihoods. The aftermath was characterized by substantial economic losses, extensive loss of species and habitat, as well as a significant rise in land degradation. The intricate interaction of fire, climate, and human activity poses an urgent issue for the management of ecosystems and conservation endeavors (Kugbe et al., 2012). This study seeks to analyze the diverse consequences of wildfires on ecosystem services in the northern savanna of Ghana. It attempts to explore both the direct and indirect effects of wildfires on the provision, regulation, cultural, and supporting services offered by the ecosystem. In addition, possible management methods would help reduce the impact of wildfires and protect the valuable ecological services of the region (Appiah et al., 2010). Four(4) objectives were proposed to facilitate the attainment of the purpose of this work:

1. Assessing the occurrence and pattern of wildfires in the northern savanna region between 2000 and 2021 by utilizing MODIS data.
2. Analyzing the key drivers of wildfires.
3. Assessing wildfires' direct and indirect effects on the provision, regulation, culture, and supporting ecosystem services.
4. Suggesting management and mitigation strategies to protect the region's valuable ecosystem services from rising wildfire risks.

Through this analysis, the study aims to contribute valuable insights for policymakers, land managers, and stakeholders working towards sustainable management of Ghana's savanna ecosystems in an increasingly fire-prone environment.

2 Methods

2.1 Study Area

Figure 1 is the geographic location of the study area showing the five main regions in Northern Ghana. The study concentrates on the Northern Savannah ecological zone of Ghana which covers the bulk of the northern part of the country with an area of about 99,182 km 2 (41% of the total land area) but only 17.1% of the population. It lies between latitudes 8°N and 11°N and has a land area of 97702 km^2. It comprises the Upper West, Upper East, Savannah, North-East, and Northern regions and is the most sparsely inhabited.

The region has a tropical continental climate classified as Köppen's Aw, with a strong seasonal rainfall pattern characterized by distinct wet and dry seasons (Ahmad & Wanah, 2024). Precipitation is concentrated from May to September, peaking in August (Amos, Ahmad, Abashiya, & Abaje, 2015; Ahmad & Wanah, 2023). The average annual precipitation is about 863.2 mm.

Hydrologically, the region is located in the Gongora Basin, part of the Upper Benue Trough Plain in northeastern Nigeria. The inhabitants are primarily engaged in agriculture, raising livestock and cultivating crops for subsistence and export. The most important crops for domestic and international markets include rice, maize, and beans (Ahmad & Wanah, 2023).

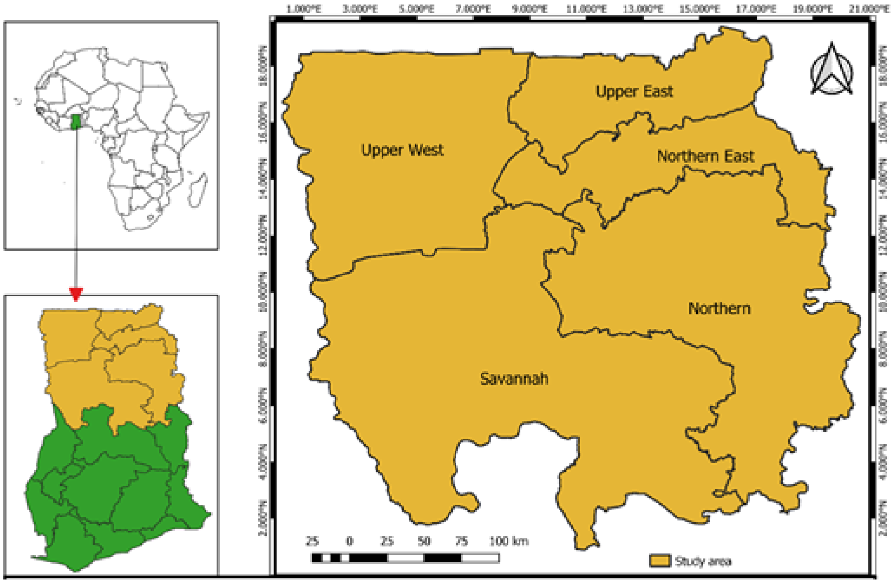

Figure 1: Study Area Map with the 5 regions where data was collected from.

2.2 Climate, Ecological, and Soil Characteristics of the study area

The northern savanna of Ghana is characterized by a semi-arid climate, primarily influenced by two distinct air masses: the hot, dry, and dusty North-East Trade Winds (Harmattan) from the Sahara Desert, and the cold, moist South-West Monsoon winds from the Atlantic Ocean (Incoom et al., 2020). This region hosts the largest vegetation types in Ghana, comprising the Guinea savannah and Sudan savannah. Important tree species include baobab, dawadawa, and shea nut trees, which are mostly scattered throughout the landscape.

The study area experiences a mono-modal rainy season with an annual mean rainfall of approximately 1250 mm to 1750 mm and a mean temperature ranging from 27°C to 36°C (Incoom et al., 2020). These climatic conditions make the area suitable for agriculture, with most inhabitants predominantly engaged in farming. Over three-quarters of households in these areas participate in subsistence agriculture (Acheampong et al., 2021). Consequently, agriculture remains the dominant land-use activity, with several small farm fields visible during the rainy season. Major crops cultivated include maize, sorghum, millet, groundnut, and yam.

Table 1: Summary of Characteristics of the Study Area

Characteristics	**Savannah Ecological zone**
Climate	Semi-Arid
Rainfall Patterns	Mono-modal
Major Average period	May to September
Annual Average Rainfall	1250-1750 mm
Monthly Average Temperature	$25°C$ and $36°C$
Soil Types	Savannah ochrosols
Socio-economic activities	Agriculture, shea butter processing

2.3 Data Collection

This study relied on a combination of field observations, literature review, and analysis of the wildfire and some vegetation data. This study, conducted for 21 years (2000 to 2021) involved annual fire data downloaded at the peak of the seasonal evolution of wildfire (December) for each year. The wildfire occurrence in the Savannah eco-zone of Ghana were assessed using the Collection 6 (C6) wildfire data of the Moderate Resolution Imaging Spectroradiometer (MODIS). Specifically, collection 6 MODIS Global Burned Area Product (MCD64A1) (https://ladsweb.modaps.eosdis.nasa.gov/search/order/) which provides daily global 500m resolution summarized in monthly data was utilized to map the annual fire occurrence (Annual Burn Area) (Giglio et al., 2018). In addition to the fire data, this study used various exploratory variables including climatic data (daily 30-year climate data retrieved from the NOAA National Climatic Data Center online data retrieval tool (https://www.ncdc.noaa.gov/cdo-web/search)); i.e., precipitation, relative humidity, maximum temperature, and wind speed. Based on MODIS data that was overlayed in the zone and based on the frequency of occurrences of wildfire provided by the MODIS data, five risk categories were identified, i.e. very high, high, medium, low and very low. A simple random sampling approach was used in selecting the locations from the categorized areas totaling 30 sampling sites A single rectangular plot measuring 30 m x 30 m was established to conduct a phytosociological inventory of the woody, regeneration, and herbaceous species components (Toko & Sinsin, 2011). The corners of the plot were georeferenced using a handheld GPS device with an accuracy of ±3 m

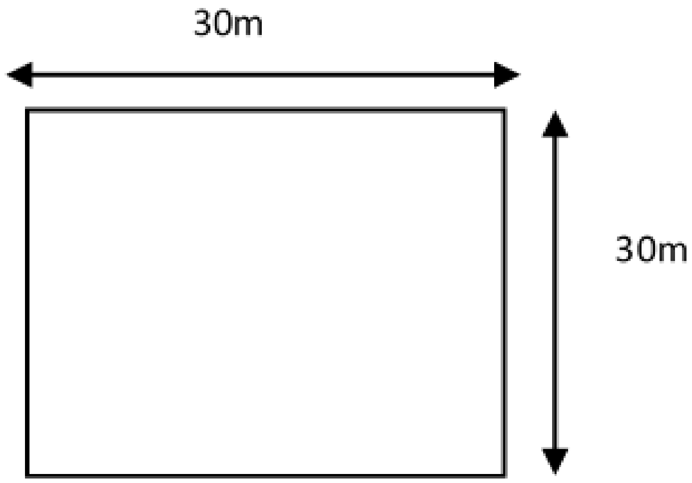

Figure 2: Plot measurement for phytosociological inventory of tree species.

All woody plants with a diameter at breast height (DBH) $\geq$ 5 cm were measured for physical parameters such as height and crown diameter, with a particular focus on frequently burnt life forms to assess regeneration dynamics. Human disturbance factors, including fire, farming, cutting, and pasture, were recorded through field observations along with the geographical coordinates. Additionally, soil types were observed as part of the data collection process (Fousseni et al., 2011).

2.4 Data Analysis and Processing

Using the ”Kendall” package in ”R”, the Mann-Kendall test was employed to analyze the trend of wildfires over a 21-year period, tested at a significance level of $\alpha = 0.05$. This non-parametric trend test is a refinement of the original test developed by Mann (1945) and later adopted by Kendall (1975). The Mann-Kendall test is used to detect the existence of a single overall trend within a time series. A positive Kendall's tau indicates an increasing trend, while a negative tau indicates a decreasing trend.
A multiple regression analysis was carried out to predict fire resistance species based on various factors such as the degree of damage sustained in a fire (Dependent variable) and the plant height, bark thickness and resprouting ability, and soil type (Independent variables). This was carried out using, the 'lm' function in "R". Descriptive statistics (Minimum and Maximum values) were used to present findings on fire frequency, burned areas, and species distribution whilst incorporating the findings from previous research to provide context and support for their observations, particularly in discussing the indirect effects of wildfires and potential management strategies. Bar charts for frequency and time series plots for trends were used to visualize the data analyzed.

2.5 Overview of Ecosystem Services in Ghana's Northern Savanna

Ghana's northern savanna offers an array of ecosystem services that are crucial for both local communities and the wider environment. The Millennium Ecosystem Assessment (MEA, 2005) highlighted four main categories of ecosystem services: provisioning, regulating, cultural, and supporting services.

- Provisioning services include food derived from cropping or animal/livestock farming, fuel wood, medicinal plants, and construction materials (Antwi et al., 2014). The many endemic plant species that the savanna hosts contribute essential local income and food for families.
- Regulating services encompass carbon sequestration, water purification and regulation, as well as flood and erosion management (Jo et al., 2024). Although minute, these services can significantly reduce climate change impacts and maintain environmental stability.
- Cultural services provided by the northern savanna include spirituality, traditional knowledge, and ecotourism (Campion & Acheampong, 2014). These services are vital to local culture and tradition.
- Supporting services such as nutrient cycling, soil formation, and primary production underpin all ecosystem services (Attuaquayefio & Folib, 2009). They are fundamental to the long-term sustainability of the savanna ecosystem and its ability to provide other services.

3 Data Analysis and Discussions

3.1 Wildfire Patterns in the Northern Savanna-Frequency and Seasonality

In Ghana's northern savanna, wildfires happen all the time, but they have clear trends when it comes to how often they happen when they happen, and what causes them. To figure out how these trends affect ecosystem services, you need to understand them. Historical trends indicate a gradual increase in wildfire frequency and intensity over the past decades, due to climate change and changing land-use patterns (Dwomoh et al., 2019). This trend has significant effects on how long ecosystem services will be sustainable in the region. Wildfires in the northern savanna typically occur during the dry season, which spans from November to April (Dwomoh & Wimberly, 2017). Data was derived from MODIS from 2000-2021 to determine the seasonality and establish a relationship between active fires and burn areas.

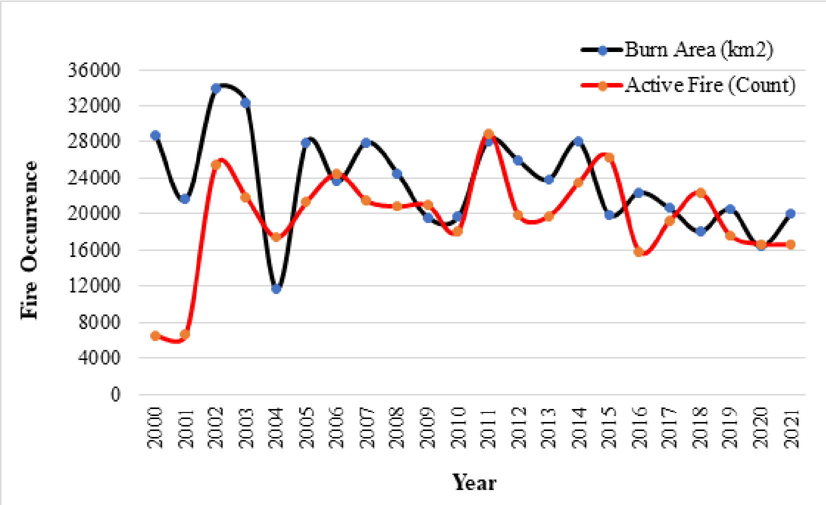

Figure 3: Burn area and active fire occurrence in Ghana's northern savanna zone from 2000 to 2021.

The analysis revealed a total count of 432,153 active fires, which burned a total landmass of 515,822.7 km2 of vegetation in the Savanna Zone. As shown in Figure 1, the highest wildfire occurrence was recorded in 2011, with 28,943 fire detections representing 6.7 percent of active fire counts whereas, the highest burn area happened in 2002 with 33883.4 km2 signifying 34.8 percent of the entire savanna zone. Conversely, the lowest occurrence of active fires was recorded in 2000 with 6501 active fire detections representing 1.5 percent of the total active fires from 2000 to 2021 while the lowest burn area was observed in 2004 occupying an area of 11,687.5 km2 signifying 12.0 percent of the entire savanna zone (Figure 1). Archibald et al. (2010) also used satellite data analysis to show that some areas experience annual burning, while others burn less frequently, creating a mosaic of fire regimes across the savanna landscape. Wildfires in this region have both natural and anthropogenic origins. Lightning strikes can ignite fires, particularly at the onset of the rainy season. However, human activities land clearing and preparation for agricultural practices, flushing out game animals during hunting, burning by pastoralists to promote new grass growth for livestock and indiscriminate disposal of cigarettes are the predominant causes of wildfires (Amoako & Gambiza, 2022).

3.2 Drivers of wildfires

Although climate is considered a primary driver of wildfire activity through its influence on weather conditions and fuel availability, the analysis (Figure 4) shows that the best predictors of wildfire occurrence are a combination of various variables; distance to settlements, slope, distance to road, maximum temperature and elevation was found to have a relatively higher performance. According to studies, fires occur more frequently near towns than farther away (Elliott et al., 2009). This is likely due to increased human activity and ignition sources near populated areas. Literature also points out the fact that areas more than 500m farther away from settlements experience more frequent fires as compared to areas closer to settlements (Elliott et al., 2009). Also, distance to roads influences fire patterns, affecting both ignition sources (e.g., discarded cigarettes) but may have higher ignition rates but potentially quicker response times for fire suppression. The additional fires in areas farther from settlements tend to occur late in the dry season, likely due to less effective fire management and suppression efforts in remote areas away from settlements. Studies show that maximum temperatures significantly impact wildfire occurrence. Higher temperatures, combined with a lack of precipitation, increase fuel dryness and flammability, leading to more frequent and intense wildfires (Abatzoglou & Williams, 2016; Turco et al., 2016). Temperature is the most important factor in wildfires. High concentrations of wildfire hotspots are found in regions like West Gonja, North Gonja, Mamprugu Moagduri, Sissala East, and Saboba, attributed to moist semi-deciduous high forest vegetation and steep slopes.

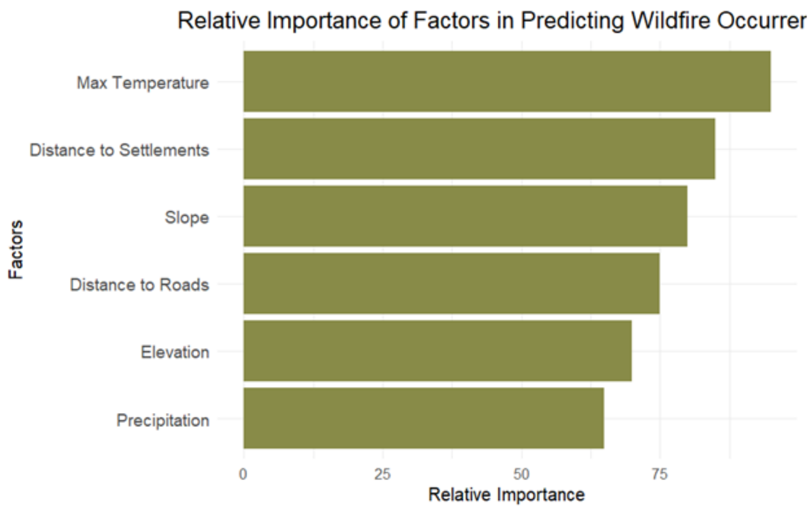

Figure 4: Factors contributing to the occurrence of wildfires in northern savannah zone of Ghana

3.3 Direct Effects of Wildfires on Ecosystem Services in Northern Ghana's Savanna

The savanna ecosystem provides numerous ecological and economic benefits. It supports a rich biodiversity, including many endemic plant and animal species. Economically, the savanna is crucial for livestock grazing, fuelwood collection, and the harvesting of non-timber forest products such as shea nuts and dawadawa fruits. Agriculture is also a significant land use, with crops like millet, sorghum, and maize being widely cultivated.

Wildfires dramatically alter vegetation structure and composition, affecting both provisioning and supporting services. Intense fires can kill mature trees, reducing woody biomass and altering habitat structures (Cardoso et al., 2018). This loss of biodiversity can disrupt pollination services and reduce the availability of medicinal plants and other non-timber forest products (Tom-Dery et al., 2014). These savannas are part of the larger Sudanian savanna belt that stretches across West Africa and are broadly classified into two main types: the Guinea savanna and the Sudan savanna. This ecosystem is characterized by a higher tree density and diversity compared to the Sudan savanna. Common tree species in this zone include Vitellaria paradoxa (shea), Parkia biglobosa (dawadawa), Adansonia digitata (baobab), and various Combretum and Terminalia species. Species composition and diversity were carried out on 30 plots of 30x30 meter land within the study area. Figure 5 illustrates the dominance of Vitellaria paradoxa among fire-resistant species in the surveyed areas followed by Parkia Biglobosa with 20 species. Piliostigma thonningii was the least with 2 trees identified. However, there was also Acacia Senegal, Combretum molle and Burkea Africana. The species listed above had regenerative potential and the ability to withstand wildfires and are considered fire-adapted. A similar analysis was carried out for tree species that are highly vulnerable to wildfire. Out of these Afzelia africana (Vulnerable), Khaya senegalensis(Vulnerable) and Pterocarpus erinaceus - Endangered (EN) were found on the IUCN list of endangered and vulnerable species (IUCN, 2024). Adansonia digitata and Khaya senegalensis were also seen as highly vulnerable to fire especially at their younger stages of growth as a result of their slow growth rates that make recovery from fire damage difficult, thin bark that provides inadequate protection against resprouting ability after fire damage, sensitivity to fire at seedling or sapling stage, even if adults are more resistant and lastly, specific habitat requirements that may be altered by frequent fires.

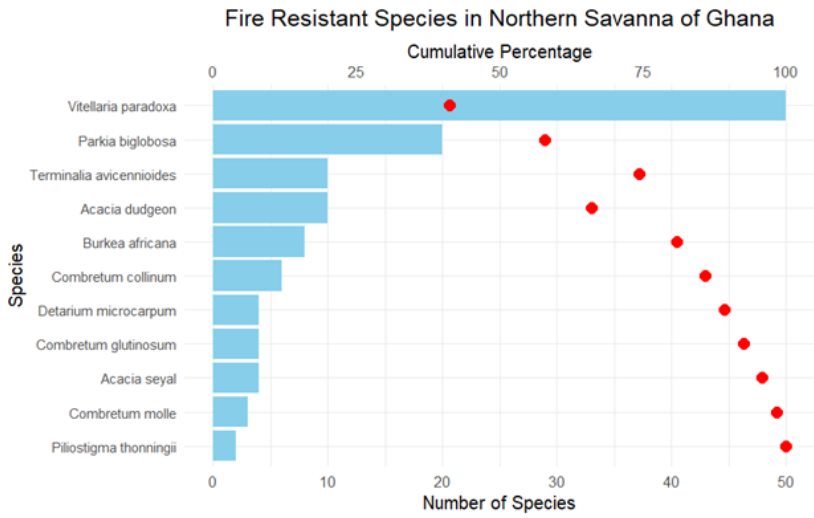

Figure 5: Distribution of fire-resistant savanna tree species identified in the field survey with red dotted points showing the cumulative percentage. Vitellaria paradoxa (shea) was the most prevalent, followed by Parkia biglobosa (dawadawa).

3.4 The Indirect Effects of Wildfires on Ecosystem Services

Wildfires are powerful ecological disturbances that can have far-reaching consequences beyond their immediate impact. While the direct effects of fire are often visually dramatic and well-documented, the indirect effects on provisioning, regulating, cultural and supporting services can be equally significant and long-lasting. These indirect effects ripple through various ecological processes, such as on soil properties and processes as a result of the increase in soil erosion, increased erosion and ash deposition impacting water quality. Air quality is another ecosystem service indirectly affected by wildfires from various literature. Smoke and particulate matter can travel long distances, impacting air quality far beyond the immediate fire area. This can have significant health implications for human populations, particularly for vulnerable groups such as children, the elderly, and those with respiratory conditions (Reid et al., 2016). This report found some interesting links between Landscape-level changes induced by wildfires and cascading effects on various ecosystem services. For instance, altered vegetation patterns can impact habitat connectivity, affect water retention and soil stability, and change the aesthetic and recreational value of landscapes. These changes can also influence the resilience of ecosystems to future disturbances, potentially altering their capacity to provide services in the face of climate change and other stressors. This finding was backed by (Turner, 2010) article which argued that ecosystems may exhibit non-linear responses to disturbances, with potential threshold effects leading to rapid and sometimes irreversible changes. In addition, the study also concluded that wildfires indirectly affect climatic conditions and hence likely to alter vegetation cover which could intend alter temperatures and rainfall patterns. These climatic changes can have implications for various ecosystem processes, including plant growth, decomposition rates, and species interactions (Holden et al., 2018). Biodiversity is another ecosystem service indirectly impacted by wildfires. While some species are adapted to fire-prone ecosystems, large-scale or high-intensity fires can lead to significant shifts in species composition and abundance. In some cases, wildfires can create opportunities for invasive species to establish, potentially leading to long-term changes in ecosystem structure and function (Bowman et al., 2009).

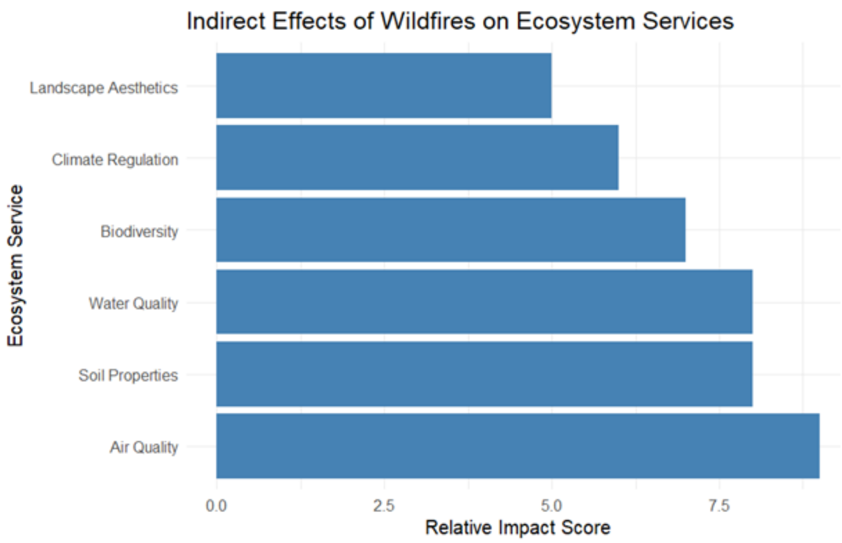

Figure 6: The indirect effects of wildfires on ecosystem services based on various literatures

3.5 Measures to reduce wildfires occurrences in the northern savanna zone of Ghana

The increasing frequency and severity of wildfires, as well as the catastrophic effects they have on ecosystems and human life, necessitate decisive action on all fronts. What follows are critical steps in creating and executing effective measures to lessen the likelihood of wildfires and lessen the severity of their effects while minimizing the financial and material losses that may result from them. Wildfire management strategies should encompass risk mitigation, prevention, suppression, and recovery plans. Sustainable, integrated planning at the landscape level is crucial. Cost-effective preventive and mitigation approaches have received less attention than repression in the savannas of Northern Ghana. Increased funding for mitigation must match upstream prevention. In addition, addressing wildfire drivers like climate change, and unsustainable land use practices is crucial for reducing their frequency and severity and should be integrated into national development strategies, including climate change adaptation and biodiversity conservation. Sufficient investment and budget should support these plans. Prioritizing fire mitigation and prevention, such as Integrated Fire Management (IFM) which seeks to combine traditional knowledge with modern techniques is essential at both national and local levels. Another measure could be developing and implementing advanced fire detection and warning systems such as using real-time satellite data to detect hotspots and predict fire spread and also create a system to send SMS alerts to local communities about high-fire risk periods. Collaborative virtual private networks (VNCs) with neighboring nations such as Burkina Faso, Togo and Ivory Coast can help combat forest fires and advance climate action.

4 Conclusion

The study reveals a growing trend of increasing wildfire frequency and intensity in Ghana's northern savanna, highlighting the need for enhanced fire management strategies. The study also highlights the complex interplay of climate, human, and topographical factors driving wildfire occurrences. Maximum temperature is a significant predictor of future fire regimes, while human factors, such as proximity to settlements and roads, have nuanced effects on fire patterns. Differential impacts of wildfires on savanna tree species and ecosystem services are also highlighted. The findings support an Integrated Fire Management approach that combines traditional ecological knowledge with modern scientific techniques, prioritizing prevention and mitigation strategies over reactive suppression efforts. Further investigation is needed to understand the long-term impacts of changing fire regimes on biodiversity and the effectiveness of fire management strategies.

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