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Assessing Social, Economic and Environmental Challenges of Veld Fires in South Africa: A Case Study of Capricorn District Municipality in Limpopo Province

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ABSTRACT

The frequency and severity at which veld fires occur in the Capricorn District Municipality of Limpopo Province and South Africa have seen a sharp increase in the past three decades. These happenings are directly linked to global warming and climate change, human negligence, changing farming techniques and population growth. The occurrences of these fires have exposed human life and properties to very high risk, loss of huge tracts of farmlands, habitats and biodiversity, accelerated unemployment and significant threat to sustainable livelihoods among the population. Using a triangulated research approach, this paper explored the root causes of veld fires in the country and weaknesses within the current policies and programmes designed to address the problems of veld fires in the country and particularly in the Capricorn District Municipality in the Limpopo Province. This paper, therefore, recommends an urgent need to strengthen existing collaborations among key stakeholders, namely, the government, farmers' associations, communities, and traditional leaders, including private organizations such as insurance companies and other financial entities. The paper further suggests incorporation of sustainable indicators and building resilience through a holistic framework for mitigating risks, and complex systems science for forest management and forest capacity to withstand the impacts of climate change.

KEYWORDS

Veld fires; community; vulnerability; community resilience; South Africa; food security

SUSTAINABLE DEVELOPMENT GOALS

SDG 3: Good health and well-being; SDG 6: Clean water and sanitation; SDG 7: Affordable clean energy; SDG 8: Decent work and economic growth; SDG 13: Climate action

Introduction

Over the past five decades, there has been a surge in the incidences of large and uncontrolled fires on all vegetated continents, irrespective of national capacities in veld fire or veld fire-management strategies (United Nations Department of Economic and Social Affairs [UNDESA], 2021). Changes in climate and global warming have contributed significantly to this phenomenon and will contribute greatly to the future occurrence of wildfire globally (Forsyth et al., 2010). The recent Intergovernmental Panel on Climate Change (IPCC, 2021) report states that hot, dry, and windy weather has increased the frequency and intensity and predicted that this weather phenomenon will continue to influence the occurrences and intensity of veld fires globally. Similarly, the United Nations Environmental Programme

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(UNEP, 2022a) disclosed that the anthropogenic changes to climate have resulted in dry lightning, stronger winds, lower humidity, droughts, and warmer temperatures. Furthermore, anthropogenic land use changes from demographic perspectives to land management have resulted in extended veld fire seasons across the world. Additionally, Dube (2015) indicated that not only is the average veld fire season 4 to 5 months longer than it was a few decades back, but the number of large annual fires has tripled globally, thereby burning twice as many acres, with severe heat and global warming as the identified root causes of veld fires. Many scholarly literatures including Nyamadzawo et al. (2013) and du Plessis and van Zyl (2021), concur that natural activities such as lightning is a natural event and not because of an anthropogenic activity, campfires, discarding lit cigarettes and negative farming practices are responsible for starting almost 80% of veld fires globally. To support this assertion, UNEP (2022b) opined that human activities have modified the climate and landscape contributing to the intensity of wildfires and increasing occurrences in places that previously did not experience wildfires. Besides the human factors, natural events such as lightning, volcanic eruptions and meteorite happenings have also contributed to veld fires worldwide (Dube, 2015).

Globally, veld fires or wildfires have dual or mixed effects on the environment; some scholars such as Halofsky et al. (2020) and Glassman et al. (2023) opined that wildfires have ecological benefits, which include enhancing growth of new plants, nutrient cycling, minimizing invasive species and increasing habitat diversity, in contrast to the broad and long-lasting negative implications on the economic, social and environmental development (Mabaso et al., 2020). These authors stated that, notwithstanding the ecological benefits, veld fires have direct and indirect economic impacts such as lost assets, businesses, and firefighting costs. The UNEP (2022a) reported that the financial costs of responding to wildfires exceed costs in wildfire management and recommended that governments shift spending toward planning, prevention, and preparedness of fires. The report states that "commonly, more than half the expenditures related to wildfires are for responses, while planning typically receives just 0.2% of the global total budget," (UNEP, 2022, p. 3). The indirect, economic costs of wildfires include reduced income from tourism, impacts on the productivity of forest industries, devalued real estate, health expenditures, and the costs of post-fire rehabilitation of ecosystems and residential areas (UNDESA, 2021). Socially, veld fires have serious implications on humans; these include increased fatality, destruction of homes and infrastructures, and negative impacts on the physical and mental health of people. Lelieveld et al. (2015) concurred that globally, veld fires have contributed to over 8% or 3.3 million premature deaths each year from poor air quality. Impacts also include increased eye irritation and corneal abrasions, psychological effects, post-traumatic stress disorder (PTSD), depression, and insomnia; these are serious health-related challenges (UNDESA, 2021).

Veld fires happening in South Africa are not different from the global trends in terms of frequency, severity and implications for the environment, socio-economic development, and sustainable livelihoods (Strydom & Savage, 2016). While some researchers such as Kraaij et al. (2018) and Dube (2015) argue that veld fires play a natural role in many ecosystems by clearing out old, dead vegetation and creating space to enable new plants to grow and thrive, which result in greater biodiversity. The ferocity of veld fires in South Africa has, in the past five decades, including major catastrophes in many parts of the country, however, significantly out weighted the above-mentioned advantages. Forsyth

et al. (2010) disclosed that between January and August 2007, 61700 plantation forests were burnt in KwaZulu-Natal and Mpumalanga, covering 2,9% and 9,5%, of the total area of plantations, respectively, in these two provinces. The Forestry of South Africa (Forestry SA), cited from Grobbelaar and Visser (2021), estimated the value of standing timber burnt amounted to R1,33bn (2007 prices); regrettably, 40% of these assets are unsalvageable (Dube, 2015). As with the rest of the world, several factors contribute to veld fires in South Africa. Strydom and Savage (2016) linked climate change to fire frequency in the country. These authors are of the view that an increase in air temperature, together with events such as the La Nina significantly contribute to veld fire occurrences. Numerous works of literature including Choga et al. (2017), Chinamatira et al. (2016), Nkomo and Sassi (2009) stated that human factors such as pastoral farming, disposal of cigarette stubs and burning of vegetation during field preparation contribute to over 95% of veld fires, while natural events such as lightning and volcanic eruptions account for barely 5% of all veld fires occurrences in South Africa.

The Capricorn District Municipality is among the districts highly prone to veld fires (Kempem, 2022). Centre for Scientific and Industrial Research (CSIR, 2020) statistics show that in 3 months, namely July, August, and September, during the fire season of 2018, the district experienced veld fires incidents which burnt 52 111.44 ha of land. In the subsequent year, in the same period, an estimated 27 928.62 ha were burnt, extending to Polokwane, Mole Mole, Lepelle and Nkumpi local municipalities. ForestrySA (2018) disclosed that the fire destroyed communities, farms, and livelihoods worth over 2 billion Rand. Similarly, the Statistics of South Africa StatsSA (2020) report indicated that the district's veld fires had taken a heavy toll on people and the environment in many communities, from the loss of human lives and property to the destruction of vast tracts of land and vegetation. The aftermath was marked by substantial economic losses, countless losses of wildlife and habitat, contributing to an escalation in Greenhouse Gas (GHG) emissions. Bond et al. (2017) opined that apart from social and economic loss, a significant number of the population endured pervasive health complications due to extensive smoke pollution under atmospheric conditions during winter in the district. The UNEP (2015) report alluded that the persistent occurrences of veld fires in the district and South Africa contribute to the "reversal of progress" concerning the Sustainable Development Goal Agenda four (SDG4), which stresses the reduction of mortality of children under 5 years and the reduction of non-communicable diseases. Sadly, despite the obvious adverse impacts of veld fires in the country, the level of education, investments and actions to mitigate the risk and impacts of veld fires in the province and the Capricorn District have not been sufficient to meet the growing threat.

Considering this alarming situation, many scholars and commentators researching these complex issues associated with environmental, economic, and social impacts of veld fires have proposed different models and strategies to address these challenges. For instance, a study conducted by Samara et al. (2015) illustrated how sustainable indicators could be effectively used to assess land use planning on a small Greek island, with similar and comparable environmental, social and economic characteristics of Capricorn District Municipality. Their findings established that many land use strategies still lack resilience, which poses a threat to long-term sustainability. Tampekis et al. (2023) proposed building resilience through integrated frameworks, critical for reducing risks and improving the adaptive capacity of both communities and ecosystems. Similarly, Tampekis et al. (2024)

propounded the notion of applying principles from functional complex systems science to forest management, which will strengthen forests' ability to cope with the effects of climate change. Kruger et al. (2006) also proposed a classification of veld fire risk in South Africa using the first instance of ecological information as a strategy for implementing new legislation to address the threats of veld fires nationally. Strydom and Savage (2016) advocated an integrated approach of combating the effects of climate change on increasing veld fires in the country. Ntekenning (2016), on the other hand, supported an amendment to the definition of veld fires. The author believes that a critical definition of veld fire will lead to practical strategies to address the problem, while Govender et al. (2012) encourage the use of Geographic Information Systems and mapping techniques to combat veld fires in the country. However, what is missing in the various literature is the impact of veld fires on the vulnerable communities and pragmatic strategies in addressing the problem. Considering these gaps, this paper explored the negative impacts of veld fire on the vulnerable communities in the Capricorn District of the Limpopo Province, South Africa, under the following objectives:

- To identify the causes of veld fires in the Capricorn District
- Determine the impacts of veld fires on social and economic issues, and the environment and,
- To assess the current legislation and policies and strategies to improve veld fire management in the Capricorn District.

The remainder of the paper is divided into five sections. The literature review within the global and South African context of veld fires is covered in section two; the third section explores the study's methodology, while section four outlines the empirical evidence and analysis of the research; finally, sections five and six present the study's discussions and recommendations.

Literature review

Causes, trends, and projection of veld fires on global and South Africa perspectives

Veld fire is used in this paper to describe any unplanned and uncontrolled fire started on shrubs or forests (UNDESA, 2021). This term predominates in Southern Africa and has been increasingly used everywhere in the region. Nevertheless, the terms bushfire and forest fire are used in Australia and Europe and some countries in Western Africa, respectively (Trucchia et al., 2020). Other terms are also used to describe the same phenomenon depending on the type of vegetation burned (landscape fire, vegetation fire, wildland fire, and grass fire) or the context in which they occur (e.g., wildland-urban interface fire, rural fire, and peat fire). However, the fire phenomenon, the combustion of vegetation in an open environment, follows the same physical and chemical laws everywhere (Tedim et al., 2020). Veld fires are regarded globally as a development issue because their impacts are multi-dimensional, affecting various socio-economic sectors and, in turn, having consequences on lives and livelihoods (Ampaire, 2016). Strydom and Savage (2016) and Dube (2015) concur that veld fires will continue impacting social and economic development goals by increasing poverty levels, food, and water insecurity, stagnating economic growth, worsening gender

inequality, and deteriorating the health of the population. Globally, different conditions have been acknowledged as the root causes of veld fires, determining the different lengths, severity and varied impacts they have on both the natural and human environment (Dube, 2015). Climate change, for example, triggers extreme weather conditions such as long hot spells with low humidity and strong winds, permitting wildfires such as those experienced in Greece in 2007, which had devastating effects (Hirschber et al., 2017).

Veld fires are a regular feature in the South African landscape, as they are across Africa, which is dubbed the "fire continent" (Strydom & Savage, 2016). Reid and Maestes (2019) posited that veld fires burnt more than two million hectares in the Free State, Northwest, Northern Cape, and Eastern Cape in 2010 alone. The worst-hit provinces were Northwest and Limpopo, recording 700,000 and 500 000 ha burned from first of May to October 2010, respectively. Run-away veld fires generally occur in hot and arid conditions. In South Africa, there are two high-risk fire seasons which follow two rainfall patterns, the dry summer season of the Western Cape and the dry winter season in the rest of the country (Govender et al., 2012). These two periods consist of heavy fuel load, which is dry leaves, wood, dead trees and grass, together with moderate to strong winds that further intensify veld fires (Choga et al., 2017). This was the case in the northern provinces of South Africa in spring 2017, with vast tracts of unusually dense dry veld ravaged by wildfires. Statistical evidence revealed that in the period between 2003 and 2014, South Africa witnessed the greatest number of veld fires due to intense heat attributed mostly to climate change (Strydom & Savage, 2016). Strydom and Savage (2016) and Forsyth et al. (2010), associate the frequency and intensity of veld fires in these periods with the warmest temperatures of 2005, 2007 and 2010, which have been cited as the warmest years on record in the southern hemisphere compared to a global average. This suggests that there are correlations between extreme weather events and veld fires. Moreover, South Africa also experiences prolonged fire seasons within a year due to the variability and short periods of the country's rainfall seasons (Kouassi et al., 2020). Figure 1 elaborates the seasons of veld fires in each province of South Africa.

Archibald et al. (2010), however, disclosed that although each province has its apex periods of fire, the records show that most of the veld fires in South Africa occur between August and September. Forsyth et al. (2010). Figure 2 depicts veld fires occurrences in South Africa

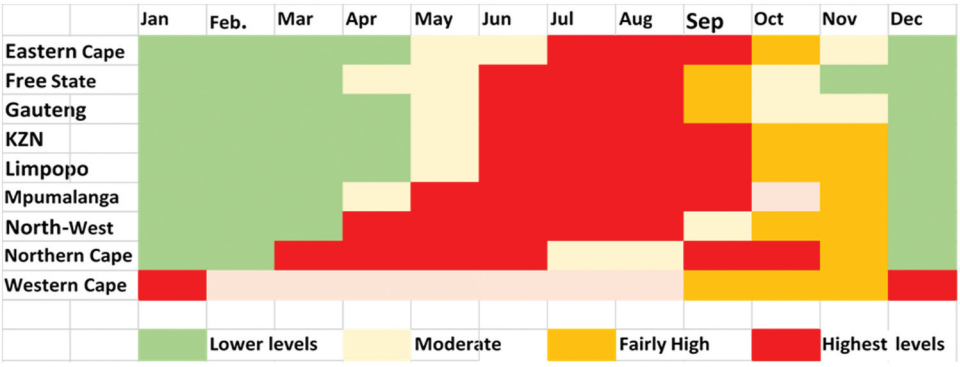


Figure 1. Provinces and expected months of veld fires. Field-based data by researchers.

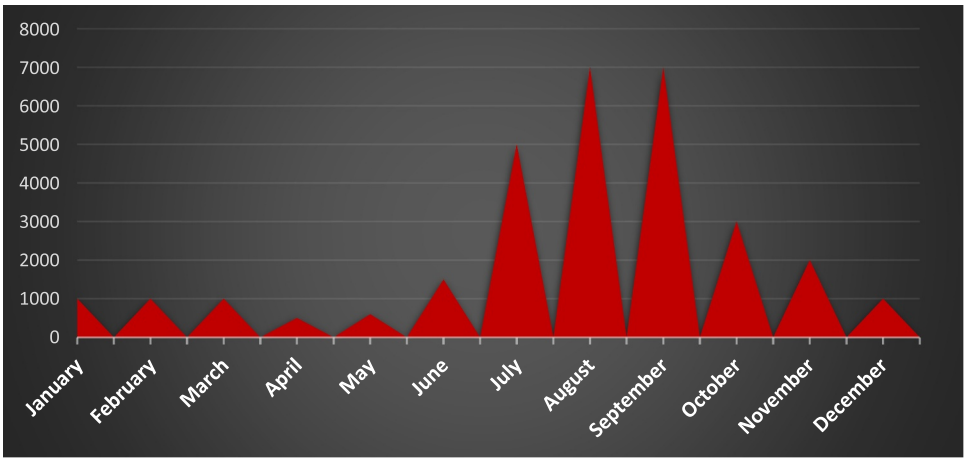


Figure 2. Average monthly trends of veld fires in South Africa between 2003 to 2013. Department of Statistics South Africa, 2018.

Numerous literatures, including projections of Cassidy et al. (2022), Strydom and Savage (2016), Kraaij et al. (2018), UNEP (2022), IPCC (2021) and Jones et al. (2022), suggest that a longer dry season, more extreme droughts and a general increase and severe aridity and climate change will lead to build up of dead plants and materials which will serve as fuel for veld fires. It is predicted that the country will witness severe dryness and its associated challenges as never witnessed before (CSIR, 2017). Lasslop and Kloster (2017) points out that climate change will be the greatest trigger of extreme lightning storms. Warmer and longer summers will heat up the land surface together with an upsurge in carbon emissions, causing stronger updrafts that are more likely to produce more powerful and frequent lightning (William's et al., 2019). The increase in GHG emissions from human activities will contribute to more fire-prone climate patterns and will increase both occurrence and intensity of veld fires in the country (UNEP 2022). Furthermore, increased levels of the fires will further accelerate global warming and climate change, threaten the balance of ecosystems, and cause more areas to be affected by fires (CSIR, 2017; UNDESA, 2021).

Policies and legislation governing veld fires in South Africa

Various pieces of legislation have been promulgated pre-and-post independence to curtail rampant fires in South Africa. For instance, the Forest Act of 1984 was a historical legislative instrument that sought to prevent and combat veld fires in South Africa (MeGranahan et al., 2016). This legislation included provisions for clearing firebreaks on common boundaries, prohibiting fires in the open-air during periods of high fire hazard, and establishing fire control committees (Sanderfoot et al., 2022). While this legislation achieved some success, the provisions of the Forest Act nevertheless reflect a historical situation that no longer exists. This law was written when the national government had substantial capacity for management throughout most of South Africa (Dube, 2013). Based on the weaknesses of the Forest Act of 1984, broader and more comprehensive legislation was enacted, namely the Veld Fire Act (Act 101 of

1998). This Act aims to prevent and combat veld, forest, and mountain fires throughout South Africa. The Act provides for various institutions, methods, and practices for achieving the purpose. The Veld Fire Act principally sought to regulate veld fires and holistically plays a critical role in veld fire management (Forsyth et al., 2010). Furthermore, the Act imposes obligations on landowners to prepare and prevent the spread of veld fires through good management or operational activities and to extinguish veld fires through procedures set out by the Act. Additionally, owners or users of land may form a fire protection association to predict, prevent, manage, and extinguish veld fires; however, the operationalization and registration as a fire protection association must be made in terms of the Act (Nyamadzawo et al., 2013).

The Disaster Management Act No. 57 of 2002 provides in Section 47, under prevention and mitigation, that Disaster Centres should assess, prevent or reduce the risk of disasters, including determining the levels of risks and assessing the vulnerability of communities and households to disasters that may occur, increasing the capacity of communities and households to minimize the risk impact of disasters that may occur, monitoring the likelihood of, and the state of alertness to disasters that may occur and develop and implement appropriate prevention and mitigation methodologies (Steenkamp, 2016). Veld fires are disasters that fall under this Act. Other Acts associated with veld fires and used to govern issues around them include the Fire Bigrade Service Act (Act No. 99 of 1997) and the National Environmental Management Act (NEMA) (Act No. 107 of 1998). Table 1 summaries the various legislations and policies regulating veld fires in South Africa.

The post-independent policies were formulated with the focus on integrated fire management with a strong emphasis on the cooperation between various government departments, spheres of government, the private sector, and communities. Nevertheless, the deployment of these policies presents its challenges due to weak institutions, lack of capacity and clarity of the role and responsibilities of key stakeholders in implementing these policies. In many cases, these mandates overlap, whilst in others, there is a lack of clarity in rehabilitation.

Method and materials

Study area

Data for this study was carried out in Capricorn District Municipality. This study area is situated in the northern part of the Limpopo province, bordering Botswana to the west and Zimbabwe to the north. The municipality covers a land area of approximately 18,628 square kilometers (National Development Plan [NDP] 2015). Based on the Demarcation Board of 2017, the Capricorn District Municipality comprises five local municipalities: Blouberg, Polokwane, Aganang, Mole Mole and Lepelle-Nkumpi. According to the latest population census by StatsSA (2015), 1.2 million people inhabit the Capricorn District Municipality, representing 23% of the total population in the province and 2.3% of the population of South Africa. The municipality's landscape is diverse, encompassing areas of savannah, grassland, and some mountainous terrain. The district forms part of the larger Limpopo Lowveld ecosystem. The municipality experiences a subtropical climate with a hot, rainy summer and mild, as well as a drier winter. The choice of this study area is strongly linked to the geographical location and frequency of veld fires in the area. The proximity of this

Table 1. Legislations and policies on veld fire management.

No.	Policies and Legislations	Functions and Responsibilities	Key Stakeholders
1.	National Forest Act of 1984	Prohibition on the making of fires in the open air, the destruction by burning of ground cover, including slash, the clearing or maintenance of fire belts by burning or the execution of block burns	The government, through the Department of Environment, Forestry and Fisheries.
2.	Fire Brigade Service Act (Act No. 99 of 1997)	The Act is the primary legislation regulating fire services and seeks to provide for the establishment, maintenance, employment, coordination, and standardization of fire brigade services. In terms of the Act, district and local municipalities are required to establish a firefighting service	The government, through the Department Environment, Forestry and Fisheries
3	The Veld fire Act (Act 101 of 1998	Promote the sustainable management and development of forests for the benefit of all Create the conditions necessary to restructure forestry in State forests Provide special measures for the protection of certain forests and trees Promote the sustainable use of forests for environmental, economic, educational, recreational, cultural, health and spiritual purposes and, Promote community forestry.	The government, through various Departments, Private organizations (NGOs) and Communities
4	National Environmental Management Act (NEMA) (Act No. 107 of 1998	The Act provides for the management of natural resources. Wildland fires have a significant impact on natural resources, with the result that the Department has embarked on a wildfire management initiative under the umbrella of the Working on Fire Programme.	Government institutions, together with the private sector and communities
5.	Disaster Management Act (Act No. 57 of 2002	The Act provides an integrated and coordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters, and post-disaster recovery, among others.	Government, NGOs, and grassroots organizations

Eastern Cape: Umbrella for Fire Protection, 2010.

district to Zimbabwe compels research into veld fires. Several literatures, including Dube (2015), Manatsa et al. (2017), and Chinamatira et al. (2016), pointed out that Zimbabwe is severely prone to veld fires in the southern region of Africa with the highest number of veld fires incidences. Due to the proximity and similar climatic characteristics between Zimbabwe and Capricorn District, the District's experiences and associated adverse effects are analogous to that of Zimbabwe.

Other factors such as the weather patterns, vegetation type and farming practices contribute to the pervasiveness of fires in the study area. This municipal area is predominantly semi-arid and dry to hot weather conditions and is regarded as one of the hottest regions in South Africa with an average daily high temperature of 28° Celsius (Rankoana, 2020). The rainfall trend is on average below 400 mm with a likely crop failure rate between 75% and 90% per annum. The rainfall in the district is highly seasonal with 95% occurring between October and April, often with a mid-season dry spell during critical periods of crop growth (Mpandeli et al., 2019). The relative humidity in the district is comparatively low, with daytime average of about 30% in winter and about 40% in summer (Nyoni et al., 2021).

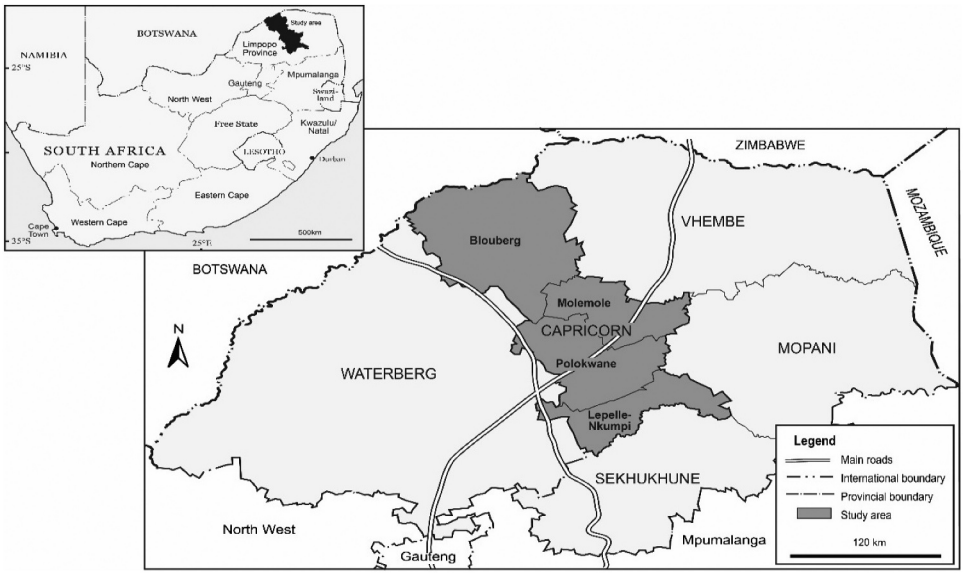


Figure 3. The map of the Capricorn District Municipality. A map of Capricorn District Municipality. Cartography Unit; Wits Department of Geography and Environmental Studies (2022).

However, much higher values are reached in the morning, nearing 60% in winter and more than 70% in summer (Nyoni et al., 2021). The municipal area's vegetation types are characterized by "makhado" mixed bushveld, small portions of arid sweet veld and "mamabolo" mountain bushveld around "mogoshi" mountains in Matlala; also, Polokwane plateau grassland vegetation type (Scheiter et al., 2018). The most common trees found in the area include acacia species (caffra, eriebola, karro), marula trees, "terminalis" species, and "euphorbia ingens" (Mosina & Maroyi, 2016). Maema et al. (2016) highlighted that the "mamabolo" mountain bushveld is the most sensitive vegetation type because of their diversity and its poorly protected status. The varied climate in the district allows for a variety of farming practices from pastoral farming activities to crop production (Whitbread et al., 2011). The area is noted for a wide variety of agricultural produce ranging from tropical fruits such as banana and mangoes to cereals and vegetables. It is also famous for rearing animals such as cattle, goats, sheep, and chickens, both on a subsistence and commercial basis. Due to lack of resources among a significant number of farmers, it results in negative farming techniques such as bush burning and campfires which often result in veld fires (Nyamadzawo et al., 2013). Figure 3 revealed the study site.

The study design

This study employed a concurrent mixed-method approach of qualitative and quantitative procedures to obtain pragmatic insight and understanding of veld fires in South Africa and the Capricorn District. Creswell (2003) described the mixed method as an approach that combines both qualitative and quantitative methods in a study simultaneously. This means it is more than simply collecting and analyzing both kinds of data. It entails using both approaches in tandem so that a study's overall strength is greater than qualitative or

quantitative research (Rahman, 2017). Considering the nature of the topic under study and the desire to offer a thorough analysis of the social, economic and environmental challenges posed by veld fires, and also place greater emphasis on resilience-building strategies as well as integrating the framework proposed by Tampekis et al. (2023) and the complex systems science approach introduced by Tampekis et al. (2024), a mixed-method approach is ideal as it consent for a more comprehensive evaluation of how communities and ecosystems adapt to external shocks and disturbances of veld fires. Furthermore, this method deepens the analysis and understanding of sustainable land use planning while strengthening the study's overall methodology. Additionally, the mixed-method approach was appropriate for capturing the complex dynamics of veld fire impacts on diverse stakeholder groups. The qualitative method was used to explore individuals' and groups' perceptions and their understanding of the impacts of veld fires socially, economically, and in the context of the environment. The quantitative method was used to ascertain and explore the variables' relationship such as frequency, human activities, and the impacts of veld fires on the environment, social and economic livelihoods. The study also employed extensive literature reviews from book chapters, journals, government gazettes and previous studies on the topic under review to explore the strengths and weaknesses of the current policies and programmes designed to address veld fires in South Africa post-independence.

Sampling techniques

The respondents for this study were selected using the purposive sampling and simple random techniques. Ames et al. (2019) defines purposive sampling as a technique in which a researcher relies on his or her judgment when choosing members of the population to participate in the study. The choice of this technique as the most appropriate for this study was since the researchers were looking for respondents who are directly involved in the management of fire activities in the district and individuals that have been impacted directly or indirectly by veld fires in the past decade. In the light of these perspectives, 15 respondents were drawn from the Fire Protection Association (FPA), Working on Fire (WoF), Department of Forestry, Fisheries, and the Environment (DFFE), Disaster Management Offices, and the South African National Parks (SANParks). These institutions provided information on legislation and policies on fires, fire risk assessment, fire prevention strategies as well as community engagements and awareness programmes.

A random probability sampling approach was used to select participants for the quantitative data for this study. Random probability sampling is a technique in which every population member has an equal chance of participating in the study (Berndt, 2020). This technique was considered because it assisted the researchers in the sampling of a large pool of respondents for the survey without any prejudice or bias. A total of 500 respondents were selected from ten communities, namely: Senwabarwana, Alldays and Makgabeng in the Blouberg Local Municipality; Seshego, Moletji, Ga-Mothapo and Sekhukhune in Polokwane District Municipality and Chunespoort, Moloto and Dikgale in Aganang Local Municipality. The probability of selecting each unit in the sample was determined in accordance with the social, economic, and demographic factors of the population. The survey employed a probability proportional to size (PPS) sampling formula of **P ¼ (C/T) * S** to calculate the sampling population in each community: In this formula: **P is the proportion of the community in the sampled population, C is the population of the**

community, T is the total population and S is the sample size. This sampling technique assisted the study to achieved accurate reflection of the population characteristics of the population. The approach also ensured that a population with a larger population had a higher representation yet maintained a representative sample from the entire population.

Data collection procedure

The qualitative data for this paper were obtained through face-to-face semi-structured and in-depth interviews. The interviews were structured to obtain first-hand information on control and prevention measures, legislation, and policies as well as stakeholders' participation and awareness creation on veld fires. This approach was also used to identify the strengths and weaknesses of the current policies and legislative framework in place to address the challenges of veld fires. The quantitative data were obtained from a cumulative number of 500 respondents. Based on the above mentioned formula, a total number of 165 (70, 55 and 40) responses were obtained from Senwabarwana, Alldays and Makgabeng, respectively, from Blouberg Local Municipality, 200 replies were obtained from Polokwane Municipality made up of 75 from Seshego, 60 from Ga-Mothapo, 70 from Sekhukhune 50 from Moletji, while 135 answers were received from Aganang Local Municipality comprising 70 from Chunespoort, 50 from Moloto, and the remaining 45 were received from Dikgale. The questionnaires centered around the root causes of veld fires, the negative implications of fires and strategies for addressing the challenges.

Data analysis

The qualitative and quantitative data obtained were analyzed simultaneously. The quantitative data were analyzed using descriptive statistics of SPSS Windows Version 21. The descriptive statistics were used to summarized and describe the quantitative data, involving variables such as fire frequency, economic losses, and environmental damage. This approach provided a clear overview of the magnitude and scope of veld fire impacts. Moreover, the approach supported the study's goal of quantifying these impacts by aiding analysis of trends, patterns, and comparisons across different geographical areas and time periods. Specifically, the technique assisted data to be captured and analyzed to produce frequency tables and graphs that ensured rapid interpretations, understanding and reading of the data obtained.

The qualitative data obtained from interviews and engagements were analyzed using the thematic analysis technique. Thematic analysis is a method for qualitative data that entails searching across a data set to identify, analyze and report repeated patterns (Kiger & Varpio, 2020). The thematic analysis was employed to systematically identify, analyzed and report patterns within the qualitative data, allowing for an in-depth exploration of stakeholders' perceptions, experiences, and insights regarding veld fire impacts. This method is particularly relevant as it captures the nuanced perspectives of various stakeholder groups, including local communities, government agencies, and environmental organizations. Moreover, the method is well suited to the study's objective of understanding the social, ecological, and economic effects of veld fires, helping to uncover key issues and factors influencing stakeholders' resilience and adaptive strategies in response to fire-related risks.

Empirical evidence and analysis

Root causes of veld fires

Respondents were asked to indicate between these two variables, "natural and human causes," the root causes of veld fires in their communities and what activities contribute mostly to veld fires. Table 2 depicts the answers of the respondents.

The results of Table 2 illustrate that a significant majority of the respondents, precisely 465 respondents representing 93%, believed that human activities contribute mostly to veld fires in their communities compared to 35 respondents, translating to 7% of the respondents, who believed that veld fires are associated with natural circumstances. With reference to the human factors, a significant number of respondents, namely 28%, mentioned vegetation or bush burning by farmers as the leading cause of veld fires. This is followed by disposable cigarettes butts at 18%, fireworks and arson were mentioned by 17% and 14%, respectively. Surprisingly, only 35 respondents mentioned natural factors as the cause of veld fires. Of this figure, most respondents, equaling 85%, linked lightning as the main cause of veld fires in the country and the municipality. While 9%% mentioned drought and 3% associated cross-seam and forest fires as natural contributors.

Social impacts of veld fires

A total of 500 respondents were engaged in the survey to assess the social implications of veld fires using specific variables. Respondents were asked to cite from listed variables the social implications of veld fires in their communities. Figure 4 depicts the answers of respondents.

This bar chart highlights the social losses caused by veld fires in the Capricorn District Municipality between 2020 and 2022 depicted in Figure 4. The results suggest that the majority, 101 of the respondents, equating to 20% asserted that veld fires have contributed to the loss of life and animals; this was immediately followed by 82 respondents equating to 16% who mentioned that veld fires are threats to water and food security in their communities and even the country. Loss of livelihoods and loss to properties and assets were mentioned by 14%, while 12% agreed that it contributes to rural–urban migration. This statistical breakdown was buttressed by an interview with a director in the provincial Department of Disaster Management in Polokwane. This interviewee stated that:

> Veld fires have significant psychological impacts on the population. It comes with evacuation, loss of homes and properties and uncertainty about the future often leads to anxiety,

Table 2. The root causes of veld fires in the Capricorn district municipality between 2020 and 2022.

Human Causes	No. of Respondents	Per.%	Natural Causes	No. of Respondents	Per. %
Discarded cigarette butts	**85**	**18%**	Lightening	**30**	**85%**
Vegetation burning	**128**	**28%**	Volcanic eruption	-	-
Campfires	**55**	**11%**	Drought and El Niño	**3**	**9%**
Fireworks	**77**	**17%**	Cross-seam fires	**1**	**3%**
Machinery and accident	**57**	**12%**	Meteorites	-	
Arson	**65**	**14%**	Forest fires	**1**	**3%**
Total	**465**	**93%**		**35**	**7%**

Field-based survey in Capricorn District Municipality, 2022.



Figure 4. Social implications of veld fires in Capricorn District Municipality (2020–2022). Field-based survey.

depression, and even post-traumatic stress disorder among survivors. Similarly, community ties are disrupted, and people struggle to rebuild their lives.

A consensus that emanated from the respondents suggests that veld fires have complex social implications that encompass public health, community cohesion, mental wellbeing and human dignity.

Economic implications of veld fires

The paper explored the economic impact of veld fires in the district. Respondents were asked to mention the economic cost of veld fires in their communities. Figure 5 depicts the outcomes of respondents from the field survey.

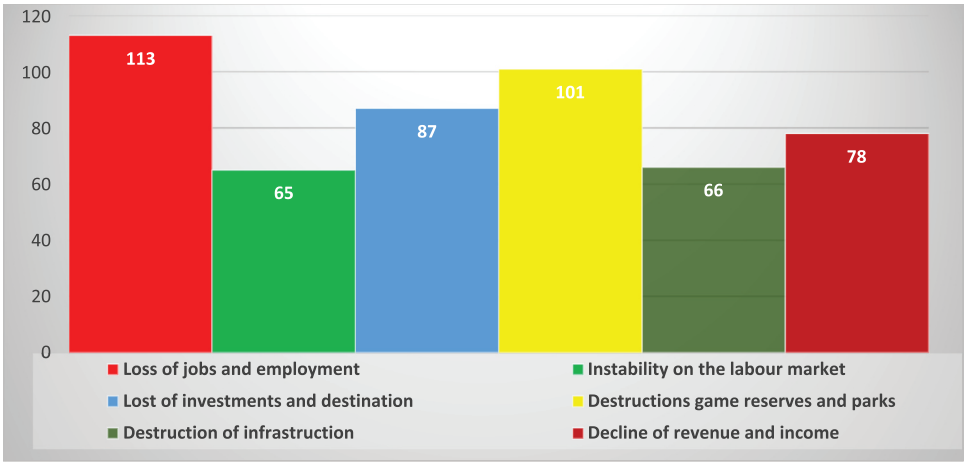


Figure 5. The economic impact of Veld fire in Capricorn district municipality between 2020 to 2022. Field-based survey.

The bar chart illustrates the economic losses resulting from veld fires in the Capricorn District Municipality between 2020 and 2022 represented in Figure 5. The findings presented in Figure 5 demonstrate that out of the 500 responses received, 113 equating to 23%, hold the view that the rampant veld fires have significant implications on job losses and high levels of unemployment in the municipality. This was followed by 101 translating to 20% who stated that veld fires have destroyed most of the game reserves and parks, 17% mentioned that the fires have led to loss of investments and destination (infrastructure?), while 16% linked this phenomenon to declined revenue and income. These statistical analyses were augmented by information provided by a provincial director: Work on Fire in Polokwane. This interviewee indicated that:

> Veld fires contribute to a range of economic costs; for instance, the 2010 veld fire, which occurred in some parts of the country including Capricorn District Municipality, caused a steep drop in overall employment and spike in unemployment and social grants. Local businesses, particularly those reliant on outdoor activities, suffered a significant loss in revenue, employment was felt mostly in the tourism and hospitality sectors, and there were corresponding drops in hotel tax revenue. Most retail employment activities in the municipality have not recovered to the pre-fire levels. (Per.com 2021 3A)

Another interviewee from a community supported these views. He disclosed that:

> Small-scale and emerging farmers often lose their livelihoods, commercial farmers lose livestock, fodder banks, machinery and equipment, and the ecotourism industry loses resorts and wildlife. Local communities also suffer greatly from the loss of important resources such as thatch grass, in these veld fires. (Per.com 2021 4A)

A common sentiment shared by most of the respondents suggested that the total economic impacts of veld fires go far beyond the cost of damages, as they include health costs and indirect losses due to power shut-offs, business closures, travel cancellations, supply chain disruptions, among other costs.

Environmental impacts of veld fires

The study carried further the implications of veld fires on the environment. Figure 6 depicts the answers of respondents in the survey.

The findings of Figure 6 suggest that of the 500 responses obtained, most of the respondents, explicitly 100 translating to 20%, stated that veld fires have contributed to the increase of soil erosion and land degradation. This was closely followed by 98 also equaling 20% who expressed the view that fires have contributed to the acceleration of habitat destruction, while 15% linked the decrease of water and air quality to veld fires. These statistical data were reinforced by a community leader who was engaged in an in-depth interview. This interviewee said that:

> Veld fires have led to severe environmental damages. Specifically, veld fires have contributed to reduced land cover, thus exposing the land to accelerated soil erosion, changes in the hydrological cycle, an increase in overland flow or surface runoff and modification in various ecological processes. Soil erosion has led to the siltation of rivers and dams, thus reducing their carrying capacity. Additionally, veld fires have destroyed a significant number of biodiversity ecosystems and some species in the environment. (Per.com 2021 4A)

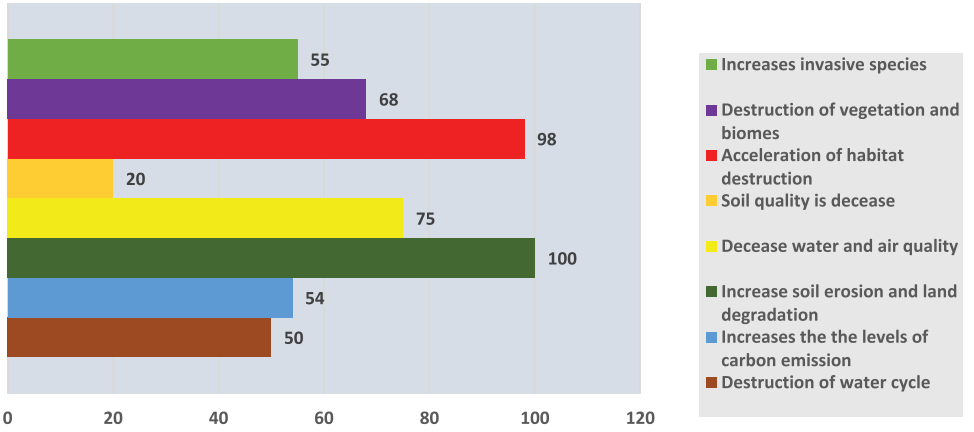


Figure 6. The environmental cost of veld fires in Capricorn district municipality between 2020 to 2022. Field-based survey.

A similar sentiment was shared by a manager of SANParks who was engaged in an interview. She stated that:

> Veld fires have a profound and distressing impact on our local environment and ecosystems. The once-thriving landscape that was home to a diverse array of flora and fauna have been transformed into charred, desolate areas, veld fires have mercilessly consumed vast stretches of forests, grasslands and wetlands that served as critical habitats for countless species. Our wildlife has borne the brunt of these devastating fires; many animals were unable to escape the rapidly spreading flames, resulting in significant loss of life, even those that managed to flee are now struggling to find suitable shelter and food in the new environment.

A common view that arose from most respondents was that there is a significant challenge to environmental management and sustainability posed by veld fires, which includes loss of biomes, reduced soil fertility, destruction of vegetation, air and water pollution and destruction of wildlife.

Appraisal of veld fire's legislation and policies

The respondents were asked to indicate whether the current policies and programmes are appropriate to minimize this problem and its impact on the population. Figure 7 depicts the answers of respondents.

Out of 500 respondents surveyed, 300 (60%) are of the view that the country does not have the right policies and strategies to address veld fires occurrences, against 200 (40%) who held opposing views. Using a "Likert scale" we calculated the respondents' views on the policies under the following variables: "Very weak/poor; Weak; Fairly good; Good and Very good." Under this formula: **[250 </= × < 500 = Outcome]** Table 3 reflects the reasons of respondents.

Out of the thirteen variables measured against the appropriateness of policies and legislation addressing veld fires, the majority, being six of them, representing 46%, were rated as weak, and four of the variables equating to 31% were rated as good, while three of the variables representing 23% were rated as good by the respondents.

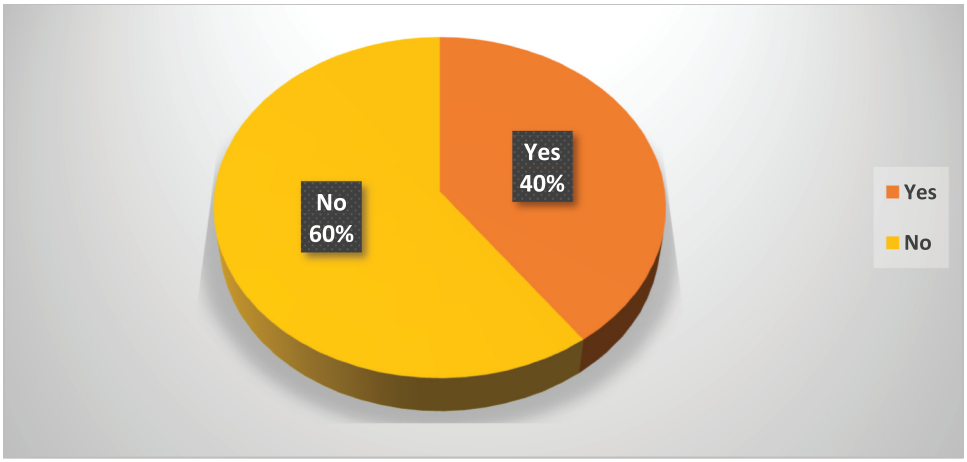


Figure 7. Evaluation of legislation and policies on veld fires. Field-based survey.

Table 3. Assessment of current legislations and policies.

Policy and legislation assessment	Very weak/ poor	Weak	Fairly good	Good	Very good	Total No. of Respondents	Overall Outcome
Stakeholders' involvement in policy planning and community needs considered	**55**	**280**	**70**	**60**	**35**	**500**	**Weak**
Integrating indigenous knowledge in policy planning and execution	**45**	**255**	**105**	**55**	**40**	**500**	**Weak**
Proactive and foresight toward the future	**40**	**55**	**260**	**100**	**45**	**500**	**Fairly good**
Abreast to innovation and modern technology	**48**	**252**	**100**	**60**	**40**	**500**	**Weak**
Policy Independent; free from political interference and manipulation	**45**	**115**	**255**	**76**	**57**	**500**	**Fairly Good**
Effective monitoring and regular evaluation practices	**43**	**257**	**105**	**50**	**45**	**500**	**Weak**
Institutional capacity, financial ability, and human capital	**37**	**263**	**110**	**55**	**35**	**500**	**Weak**
Coherency and collaboration between departments and agencies	**39**	**54**	**97**	**250**	**60**	**500**	**Good**
Transparency and accountability and information availability, and clear objectives	**40**	**100**	**260**	**64**	**36**	**500**	**Fairly Good**
Availability of equipment and resources to address veld fires	**50**	**55**	**100**	**250**	**45**	**500**	**Good**
Integrating awareness, education, and prevention mechanisms in the context of ecological, social and economic management and easy to understand	**46**	**50**	**254**	**100**	**50**	**500**	**Fairly Good**
Projection of climate change phenomena such as drought and floods	**45**	**255**	**110**	**60**	**30**	**500**	**Weak**
International collaboration and coordination	**40**	**60**	**40**	**260**	**60**	**500**	**Good**

Field-based survey in Capricorn District Municipality 2022.

Interestingly, none of the respondents regarded the current policies and legislation as being good. The statistical outcomes were anomalous to the views of a policy analyst of the provincial Department of Water and Sanitation. This interviewee posited that:

> Our policies and strategies are well-suited to address veld fires because they incorporate cutting-edge technology and a comprehensive approach to veld fire management. We focus not only on firefighting efforts but also on community education and prevention. Moreover,

> the policies lay strong emphasis on ecosystem management, by integrating controlled burns and forest thinning, we can mimic natural fire cycles and reduce the build-up of combustible materials. (Per.com 2021 5A)

Conversely, this view was in sharp contrast with the opinion expressed by a director of Fire Protection Association, an NGO based in Polokwane. This interviewee stated that:

> The current policies and strategies fail to address the root causes of veld fires, primarily focusing on reactive firefighting rather than proactive prevention. There are no comprehensive measures to reduce human activities that contribute to ignition, such as poorly managed power lines, or careless disposal of cigarettes. The policies are mainly dealing with the symptoms rather than preventing the problems.

Another employee in a SANParks indicated in an interview that:

> The current policies and programmes have overlooked the significance of community involvement and education, lack coordination and collaboration among different agencies and jurisdictions. Veld fires don't adhere to administrative boundaries, yet our policies have failed to facilitate seamless cooperation. Policies must empower residents, community organisations and other agencies to take ownership of their environment, information sharing and joint efforts to manage veld fires effectively.

Another interviewee from Working on Fire shared similar sentiments during an interview. This interviewee mentioned that:

> Climate change is a key driver of increased veld fires frequency and intensity, yet the current policies lack a comprehensive climate adaptation approach. Without addressing the changing climate patterns and influence on fire behaviour our strategies will continue to fall short in effectively mitigating the impacts of veld fires.

Some common perspectives that emanated from the engagements suggest that policies and strategies to address veld fires revolve around a multi-faceted approach that incorporates prevention, detection, response, community involvement, ecosystem management and adaptation to changing environmental conditions.

Discussion

This paper explored the social, economic, and environmental implications of veld fires on sustainable livelihoods on the vulnerable population in the Capricorn District Municipality. It further analyzed the policies and regulations designed to address the associated challenges of veld fires in the district and South Africa. Two main factors were identified as fundamental causes of veld fires in South Africa and the Capricorn District Municipality. These are human factors and natural phenomena. Findings from Table 2 revealed that most of the veld fires in the district are a result of human negligence, recklessness, and irresponsibility; however, natural factors also contributed to the disaster though at nominal scale. These findings mirror the observation made by Nyamadzawo et al., (2013); Dube (2015); Chugs, Maabong and Mphale (2021); UNEP (2022). Their studies state that human activities contribute mostly to fire occurrences in many communities in South Africa. Human activities such as open burning, campfires, equipment failure, and engine malfunction, careless burning of debris, reckless discarding of cigarettes on dry grounds, land clearing, hunting, smoking out bees for honey harvesting, and the making of fires by motorists along

highways as well as intentional acts of arson remain significant causes of fires. Findings of Table 2 uncovered that vegetation burning by farmers ranked high among the human causes of fires due to intensive cultivation of food to feed the population in the municipality. These observations are echoed by and Choga et al. (2017) that bad farming practices such as land clearing or land preparation for cultivation stand out as the greatest cause of fires generally in the country. The above-mentioned observations suggest that due to lack of information and education farmers failed to do proper assessment of factors that may ignite or spread fires, e.g. weather conditions such as wind direction, temperatures, or absence of fire guards. Apart from the human causes, findings from Table 2 also uncovered natural factors that contribute marginally to veld fires in the country and the municipality. The outcomes established that lightning stands-out as the main cause of natural fires in country. These findings are similar to the outcome of Parker (2016) who found that since 1975, the number of veld fires ignited by lightning has increased between two and five percent, driven by predominantly volatile thunderstorms and dry weather conditions, El Niño and cross-seam fires.

In terms of the social impacts, the findings of Figure 4 revealed the implications of veld fires on sustainable livelihoods of the population, especially the marginalized and the vulnerable groups. The findings uncovered that loss of livelihoods, threat to water and food security, loss of properties and assets, loss of life and animals are some of the social damages associated with veld fires. These were similar findings uncovered by StatsSA (2021) that the fatalities associated with the 2010 veld fires included 30 professional firefighters and members of communities, 41 fatalities in 2011, and an incident where 20 people died in a single fire. This was followed in 2013 when seven people lost their lives, and 118 persons were injured. A similar event was recorded in 2015 where 41 752 people had to be evacuated, and 169 homes were either partially or totally destroyed, as well as an event in 2020 where 92 homes and properties were destroyed. On 17 occasions, there was a long-term collapse of electricity services and water supplies, and national truck roads were blocked 32 times. These were similar discoveries made by Rosenthai et al. (2021) that veld fires have short- and long-term social implications, which include loss of lives, destruction of homes and infrastructure. The outcomes in Figure 4 further established that the occurrences of fires affect the physical and mental wellbeing of people leading to post-traumatic stress disorder (PTSD), depression, and insomnia that are serious health problems. These outcomes were bolstered by Lidskog et al. (2019) that fatality and property loss through fire has immediate a social impact; however, there are ripple effects that carry on for years. With the loss of property comes the displacement of individuals and families from their homes, the decimation of businesses, and severe impacts on family's insurances and financial resources. Furthermore, the findings of Figure 4 uncovered the implications of veld fires on water and food security. The underlying findings suggest that veld fire ashes contaminate water sources used for drinking and irrigation. This contamination renders water unsafe for consumption and agricultural use. These combined impacts lead to immediate food shortages, increased food prices and decreased nutritional intake in the affected communities.

Figure 5 uncovered the economic impacts of veld fires on livelihoods. These include loss of jobs and employment, destructions of game reserves and parks, devastation on tourism, loss of investments and destinations, decline of revenue and income, instability in the labor market and destruction of infrastructure. These are similar views expressed by

Nyamadzawo et al. (2013) and UNDESA (2021), that veld fires contribute to the reduction of income from the tourism sector, impacts on outputs of forest industries, undervalued properties, and the costs of post-fire rehabilitation of ecosystems. The findings in Figure 5 further established that veld fires' damage to infrastructure is directly and indirectly linked to tourism activities. These include natural attractions, water delivery systems, game reserves and parks. These, in turn, contribute to a decline in tourism and recreational activities, which negatively affects local economies. The findings of the research furthermore showed the destruction of sectors such as agriculture, forestry, tourism, and transportation, which comes with a decrease in productivity and a loss of jobs. Given that the ripple effect of veld fire damage extends across a huge geographic area and across many industries, it can be difficult to calculate the full extent of the costs of these disasters.

In terms of the environmental implications of veld fires, the findings of Figure 6 revealed that veld fires have contributed significantly to the destruction of vegetation and a variety of biomes within the environment. The findings uncovered that rampant occurrences of fires have contributed massively to the extinction of different species of wildlife and other species, reduction of soil fertility and an expansion of soil erosion in the municipality. The underlying outcomes of Figure 6 suggest that the destruction caused by veld fires extends beyond the flames themselves. Habitats are razed, vegetation lost, leading to soil erosion and degradation. The loss of vegetation removes the natural barriers that prevent erosion, increases the risk of landslides and sedimentation in the nearby water bodies. The altered landscape disrupts the water cycle, potentially leading to irregular water flow patterns and decreased groundwater recharge. Similarly, the outcomes of Figure 6 revealed that the smoke generated by veld fires contains fine particulate matter and pollutants that have far-reaching consequences. The smoke not only poses immediate health risks to human and animals but also travels long distances, affecting air quality in communities far from the site. The outcomes of Figure 6 also uncovered that veld fires affect biodiversity habitats. In the wake of fires, vast areas of vegetation are consumed, leaving animals with limited food, shelter, and reduced opportunities for reproduction. The destruction of habitat leads to population decline and extinction of certain species of plants and animals. These findings aligned seamlessly with Rosenthai et al. (2021) that veld fires have multifaceted impacts on the environment. They affect climate, air quality, biodiversity, soil health and the delicate balance of ecosystems.

Based on the interwoven challenges associated with veld fires, this paper evaluated the current policies and strategies designed to address these challenges. The findings of Figure 7 established that the current legislation and policies are not abreast enough to meet the pervasiveness and intensity of veld fires in the municipality and the country. The findings of Table 3 underscored that the policies and strategies are weak because they failed to either address or adequately integrate some critical elements into the policy planning and implementation. For instance, most of the respondents believed that the current policies lacked stakeholders' engagement and community's needs, failed to integrate indigenous knowledge into the policies, lacked foresight and innovation, are weak in effective monitoring and regular evaluation practices, and that there is fragile institutional capacity with inadequate funding to address veld fires occurrences in the face of climate change. These findings were collaborated by Malemane et al. (2021) that the current strategies to manage veld fires were formulated before the advent of democracy in 1994, where planning and implementation were still centralized, bureaucratic institutions, with little capacity to respond to diverse community-defined needs. The underlying findings in Table 3, which have been observed

by numerous scholars, including Dube (2013) and Kruger et al. (2006), revealed that communities who are custodians of knowledge on past veld fires and burning patterns are left out in decision-making and management of veldfires. Therefore, it is prudent to position the fire environment within the social-economic and ecological context, which allows for the in-depth understanding of the causal interaction between changes in policies, social systems, and veld fire management.

Conclusions and recommendations

Veld fires affect people's lives, the economy, and the environment significantly. Findings from this study revealed that the Capricorn District Municipality, as well as many municipalities in South Africa, lack clear direction regarding veld fires management. This study unequivocally established that over the past three decades, numerous policies, strategies and legislative frameworks have been enacted to address these challenges; however, most of these strategies are just ad hoc programmes and mostly reactive measures. Similarly, most of the institutions that were established to capacitate local communities and grassroots organizations against the scourge of veld fires, are severely hindered by human capacity, inadequate funding, and the alienation of key stakeholders in decision making or implementation processes. This paper, therefore, suggests that addressing the complexities of social, economic, and environmental challenges posed by veld fires requires a comprehensive and multifaceted strategy with strong collaboration between government institutions, community organization, businesses, and researchers.

Addressing the social challenges will require a focus on community engagement support. It is imperative to involve residents in veld fire prevention and preparedness efforts. This study strongly recommends a collaborative governance structure that connects local, regional, and national actors for coordinated fire response efforts. Also, to promote community-based fire management initiatives through training, public awareness campaigns, and surveillance systems. Ensure post-fire recovery systems that focus on restoring ecosystems with fire-resistant species and integrate veld fire management into broader climate adaptation and urban planning policies to enhance long-term resilience. The government must promote community meetings, workshops, and educational programmes to raise awareness about fire prevention, responsible behavior, fire risks and safety measures. Economic challenges can be addressed through an integration of incentives and diversification of approaches. The government must support communities that are heavily reliant on industries and trading activities vulnerable to veld fires by identifying alternative revenue streams such as ecotourism, agroforestry or sustainable agricultural practices that are less vulnerable to fire-related disruptions. Similarly, the government, through the Department of Disaster Management must create dedicated funds to provide rapid financial assistance to businesses affected by veld fires. These funds should be used to cover immediate expenses, facilitate recovery effort, and support job creation. In relation to environmental challenges, a mitigation strategy must be developed and implemented to actively manage and restore ecosystems. Controlled or prearranged burn must be strategically executed to minimize fuel load and mimic natural fire sequences. This will not only assist to thwart more intense and damaging fires, but also to contribute to a healthy ecosystem and enhance biodiversity. The leadership within local, provincial, and national government must

encourage ecological restoration projects that focus on rehabilitating fire-adapted ecosystems and controlling invasive species, which will enhance the overall resilience of landscapes. It is also important to protect water sources in fire-prone areas, ensuring adequate water supply for firefighting efforts and preventing water contamination caused by runoff veld fires. Additionally, this study advocates for the integration of ecological, social, and economic resilience indicators into veld fire management by prioritizing a preparedness, recovery, and adaptation approach. These involve the utilization of data-driven tools such as remote sensing and GIS for instantaneous monitoring and predictive modeling. Implementation of strict urban planning measures, including fire-resistant building codes and defensible spaces, while employing ecosystem-based management practices, such as controlled burns, to manage fuel loads effectively must be addressed.

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Disclosure statement

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

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Data availability statement

The data supporting the finding of this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restriction.

Ethics

This study adhered strictly to ethical values of research which includes consent, confidentiality, anonymity, and voluntary participation. We therefore declared that all the participants' voluntary and willingly participated in the study.

Further research

While this study highlights the social, economic, and environmental impacts of veld fires in the Capricorn District Municipality in the Limpopo Province of South, further research is required to develop standardized metrics for assessing ecological resilience to veld fires. The integration of GIS-

based remote sensing data with ecological modeling will provide precise understanding of how fire regimes impact biodiversity and ecosystem services over time.

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