STRENGTHENING RESILIENCE IN AGRICULTURAL PROJECTS BY CHARACTERISATION OF VELDFIRES USING KEETCH-BYRAM DROUGHT INDEX: A CASE OF VICTORIA STATE IN AUSTRALIA

By

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DECLARATION

I, **Toyi Maniki Michael Diphagwe**, hereby declare the research in this study to be the original result of my own efforts. With full references, all sources used and comments made were acknowledged. This mini dissertation is given in partial fulfilment of the Master's degree in Disaster Management and I also declare that it has never been presented in any form or anywhere else for any degree.

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DEDICATION

This thesis is dedicated to my ancestors and All-Powerful God, for granting me the zeal and power to complete this degree. To my lovely wife Portia Diphagwe, two sisters Kehilwe and Punini, and two brothers Itumeleng and Mosioa, who have motivated me to pursue this degree to inspire them.

ABSTRACT

The 2019 Australian veldfires burned over 27 million acres of land, 417 people died prematurely, 3 151 were hospitalized due to cardiorespiratory conditions, 3 500 individuals were left homeless and 1 315 experienced asthma attacks. Only 33 people died as a direct result of the fires. The majority of deaths and buildings destroyed were in New South Wales and the State of Victoria, which lost 3, 2 million acres of forestland. The current study therefore aimed at characterising and predicting veldfire risk in the study area using the Keetch-Byram Drought Index. A 38 year-long time series of data was obtained from an online National Aeronautics Space Administration database. The normality test was deployed using the following criteria: Shapiro-Walk, Anderson-Darling and Lilliesfors were engaged, the results for both precipitation and temperature came out not normal. Homogeneity tests for both precipitation and temperature were deployed using a non-parametric Pettitt's test and the results revealed a P-value that is above 0.05, which means that all the data sets of the stations proved to be homogenous. The plot and precipitation by Mann-Kendall trend test revealed the majority of the stations has the p-values that are less than 0.05 (significance level) and the plot and temperature by Mann-Kendall trend test revealed the p-values that are above 0.05. The Keetch-Byram Drought Index class frequency test revealed two out of eight stations with relatively high values showing moderate risk levels in terms of categories. It will take two stations 13, 19 years and three stations 38 years to reach a moderate to high fire risk category according to the KBDI return level. With this low probability, the study found the area less prone to fire risks detrimental to agricultural projects. The state of Victoria can implement more agricultural investment projects without a high risk aversion.

KEY-WORDS: Veldfires, Vulnerability, Resilience, Coping capacity, Keetch-Byram Drought Index.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACT	Australian Capital Territory
BBC	Bogardi-Birkman-Cardona
CRC	Cooperative Research Centre
EU	European Union
FAO	Food and Agricultural organisation
HVRA	Hazard, vulnerability, and risk assessment
KBDI	Keetch-Byram Drought Index
NASA	National Aeronautics and Space Administration
NSW	New South Wales
PAR	Pressure and Release model
UNISDR	United Nations International Strategy for Disaster Reduction

Chapter 1
ORIENTATION OF THE STUDY

1.1 Introduction

Serious challenges are facing the globe including changing weather patterns due to climate change, lack of access to resources, rapid population, and most importantly the impact of veldfires on the lives of people and wildlife (Climate Council, 2019). In September 2015 the United Nations adopted the 2030 Agenda for Sustainable Development Goals that contain the targets that will protect basic human rights, give assistance to the communities to recover and be resilient against future disasters, safeguard the environment and address the effects of climate change (United Nations Environment Programme [UNEP] 2020). The United Nations (UN) has mandated every government to heed the call and be innovative in the implementation of the set goals. In June 2020 Emegerncy Leaders for Climate Action (ELCA) unveiled an Australian Bushfire and Climate Plan which is a guide to solve among others the issue of poverty, inequality and build a capable state drawing from the energies of its citizens to address every hazard that might harm the society (Bushfire CRC, 2020).

The Australian continent has experienced devastating veldfires for millions of years that have shaped its landscape (UNEP 2020). Most of the veldfires have been caused by lightning, which is a natural phenomenon and human factors (Forest Fire Management Victoria [FFMV], 2019). Three decades ago, there was an increase in greenhouse gas emissions in the atmosphere which resulted in global warming. Climate change affects the rain patterns and increases evaporation, and should that continue to be the case. Veldfires and their impact will escalate (Atkin 2014). Before this study, the Forest Fire Danger Index and Grass Fire Danger Index were provided, and the projections of global warming on the fire patterns to resolve veldfires in Australia had only been done for vulnerability assessment (Balston and William, 2014).

1.2 Background of the study

Veldfires have always been part of humankind throughout history (Climate Council, 2019). For centuries, indigenous people have been using fire to hunt animals, manage the environment, and had the knowledge to control those natural veldfires (Stewart, 1956). Veldfire existence is inevitable, but people must learn how to mitigate the negative impact on the environment, wildlife, and populations BBC News (2020). Australia has experienced the worst

Veldfires in 2019 during its fire season due to high record temperatures of 1.52ºC record above average since 1950 and months of serious drought, with 40% of rainfall lower than the average since 1900 (Readfern, 2020). These fires mostly affected the eastern and southern parts of the continent, where the majority of people reside. Many of the buildings that were lost were farm buildings, adding to the challenge of agricultural recovery that is already complex due to the drought (BBC News, 2020).

1.3 Problem statement

The extraordinary bushfires in Australia have been linked to climate change, as documented high temperatures and a dry season preceded the spread of fires (Gramling, 2020). The amount of harmful smoke people inhaled during the fire season has caused more fatalities than the actual fire. The results showed that 417 people died prematurely, 3 151 were hospitalised due to cardiorespiratory complications, and 1 315 experienced asthma attacks. Only 33 people died as a direct result of the wildfires (Pickrell, 2020). More than one billion animals died during the wildfire season (Wood, 2020). Australia is one of the biggest producers of coal in the world and also one of the biggest air polluters that contribute to the climate crisis (Climate Council, 2019). In 2018, the total emissions from the mines were 670 million tonnes which are about 75% of the atmospheric air circulation (Morton, 2019).

The combination of the unprecedented wildfires, destroyed homes, millions of hectares of land burnt, families displaced and animals that died has proved to be a national threat to mental health. More than 15% of victims reported post- traumatic stress disorder, 13% reported depression and 25% turned to alcohol to deal with the psychological distress (Ducharme, 2020).

The purpose of the study is to characterise these fires using the Keetch-Byram Drought Index. The other studies did not use the commonly used conceptual frameworks for sustainable development as applied in this study with the view of providing intervention measures to policy-makers to mitigate the losses in the agricultural sector.

1.4 Aim and objectives

1.4.1 Aim

The study aims to characterise and predict veldfires using the KBDI and to provide relevant stakeholders with veldfires' full behavioural spectrum for proactive decision making towards resilience building.

1.4.2 Objectives

- To determine the trend patterns of the KBDI values in the study area;
- To determine the likelihood of veldfires in the study area;
- To determine the return levels of veldfires in the study area using KBDI; and
- To provide intervention measures for policymakers, government authorities and all relevant private stakeholders about the conditions of veldfires in the study area.

1.5 Study area description

1.5.1 Location

The study area is Victoria, a State in the southeast of Australia (Figure 1.1). The area size is 227 416 km^2 and is the smallest mainland State in Australia, as it accounts for only 3% of the total landmass. Victoria is a mountainous coastal region of the continent and Melbourne is the capital of Victoria. The State stretches about 1 680 km along the coastline of the Tasman Sea and the southern Indian Ocean (Waterson and Prescott, 2020).

Figure 1.1 Map of Victoria State in Australia (Source: Topograhic-map.com, 2012)

1.5.2 Climate

Even though Victoria has many changing climates it is classified as (Cfb) which is the temperate ocean climate according to the Köppen and Geiger climate system (Climate Data-Org, 2020). The climate is generally warm and temperate. The highest recorded maximum temperature was 47.2ºC recorded in Mildura on 10 January 1939 and the lowest minimum recorded was 12.3ºC in Mount Hotham on 13 August 1939 (Bell and Byrne, 2019). The average annual temperatures are maximum 20ºC and the minimum 11ºC (Figure 1.2), the average annual precipitation is 640 mm (Figure 1.3) and (Figure 1.4) and on average the wind is normally seen in September (Weather & Climate, 2019).

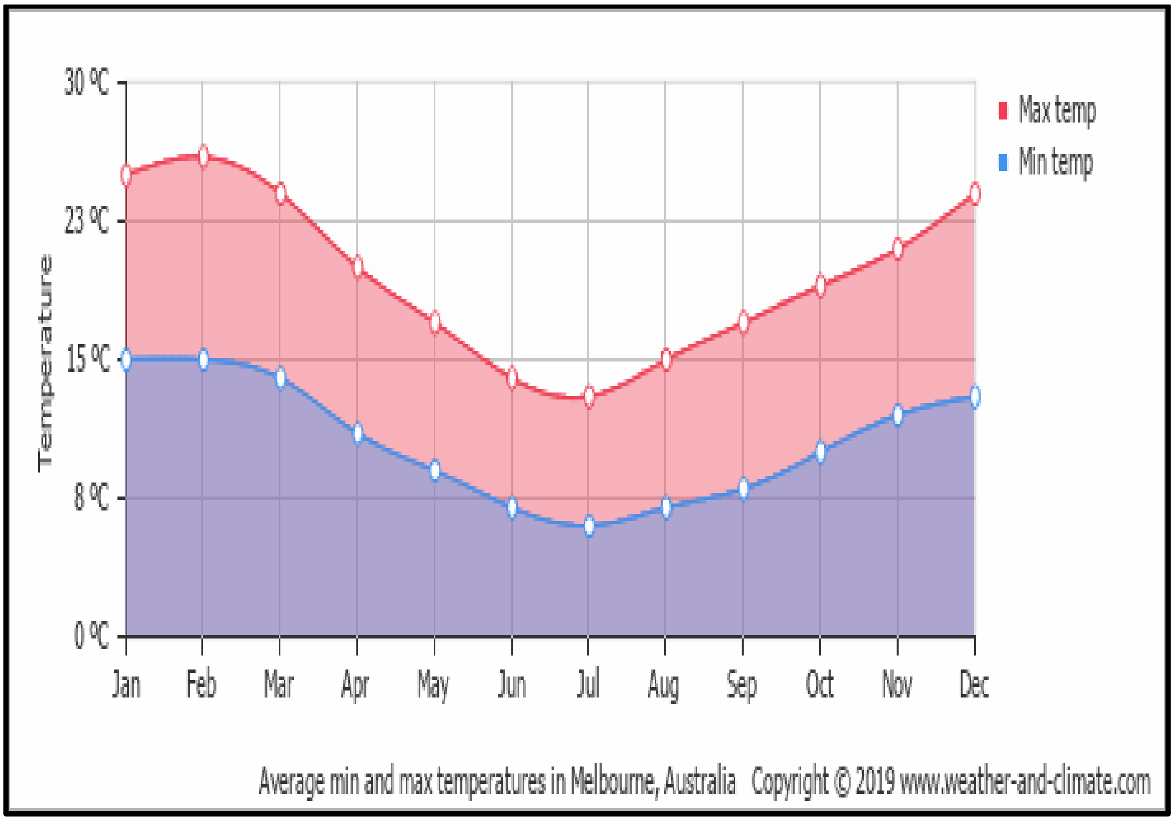


Figure 1.2 Temperatures of Victoria (Melbourne) state in Australia (Source: Weather & Climate, 2010)

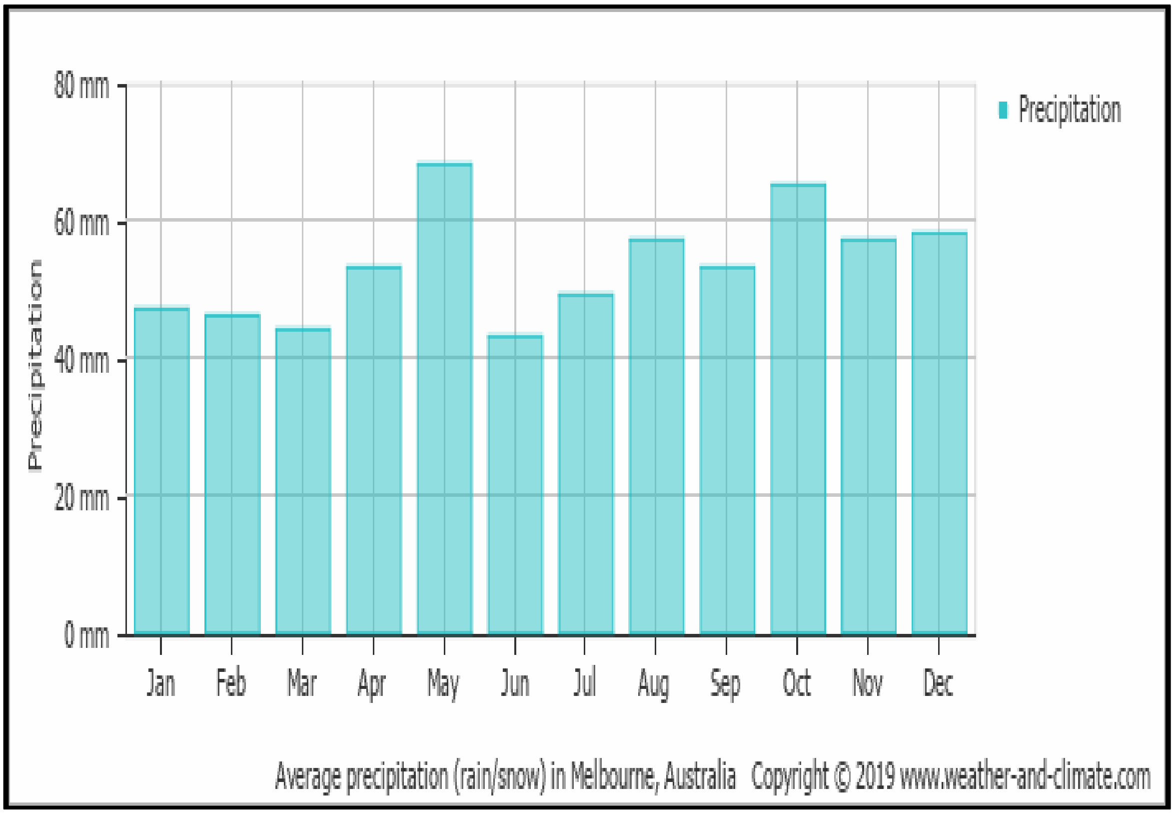


Figure 1.3 Precipitation of Victoria (Melbourne) state in Australia (Source: Weather & Climate, 2010)

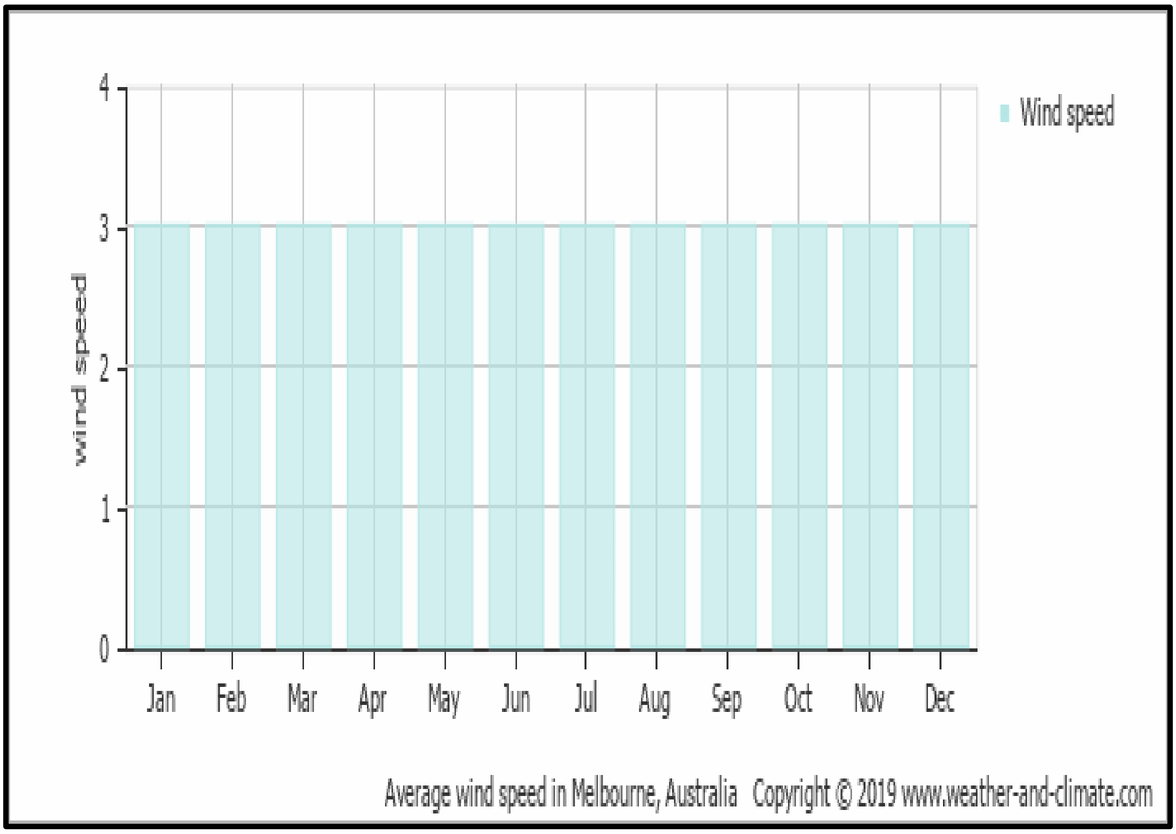


Figure 1.4 Wind speed of Victoria (Melbourne) state in Australia (Source: Weather & Climate, 2010)

1.5.3 Livelihood

Victoria is a high-income state with an unemployment rate of 5.472% for March 2020 as recorded in the report by the Australian Bureau of Statistics and it is one of the good performing states in the Asian-Pacific region according to the 2020 Index of Economic Freedom (The Heritage Foundation, 2020). Victoria prides itself on beautiful mountains, national parks, and surfing beaches, a good attraction for tourism. Over 36% of the Victoria is covered with forest and the state accounts for 25% of the population of Australia (The Heritage Foundation, 2020). The Victorian export performance report in 2017 stated that Victoria is the largest agricultural producer in Australia with 21 200 farms that sustains 77 000 people and exported $14.2 billion worth of food and fibre. After the veldfires Victoria had introduced some recovery plans to cover the cost of essential needs such as food, clothing, medication, and affected families were given $280 to a maximum of $1960 per family. Small businesses that experienced a decline in revenue over three months were supported with a grant of $10 000 (Bushfire recovery Victoria [BRV], 2020)

1.5.4 Vegetation type

Victoria has native vegetation which is a rich element to the population's heritage. Term vegetation refers to a set of plants that are occurring naturally in a specific land that delivers a different type of ecosystem benefit to make the land more productive and contribute to the well-being of wildlife, protects streams, absorbs carbon dioxide and release oxygen (Victoria State Government [VSG], 2020). The vegetation data that is collected in the state of Victoria is used for classifying the type of vegetation to plan for intervention and management, those types of native vegetation, which include tall trees, floristic, grass, mallee and woodland (Australian Government. Department of Agriculture, Water and the Environment [DAWE], 2017).

1.5.5 Topography

Topographically, Victoria (–36.59861 144.47801) has many diverse areas with Mount Bogong the highest peak at 1 986 m and alpine areas which rise to 2 000 m (Figure 1.5). There are also beautiful natural occurences such as Goulburn River, the longest river (654 km), Gippsland lakes (600 km^2), and semi-arid plains. The elevation heights of the state are at coordinates –39.19849 140.96190 to 33.98080 150.03328. The minimum elevation is: 0 m and the maximum elevation is: 2 133 m. Average elevation: is 169 m (Topographic-map.com, 2020).

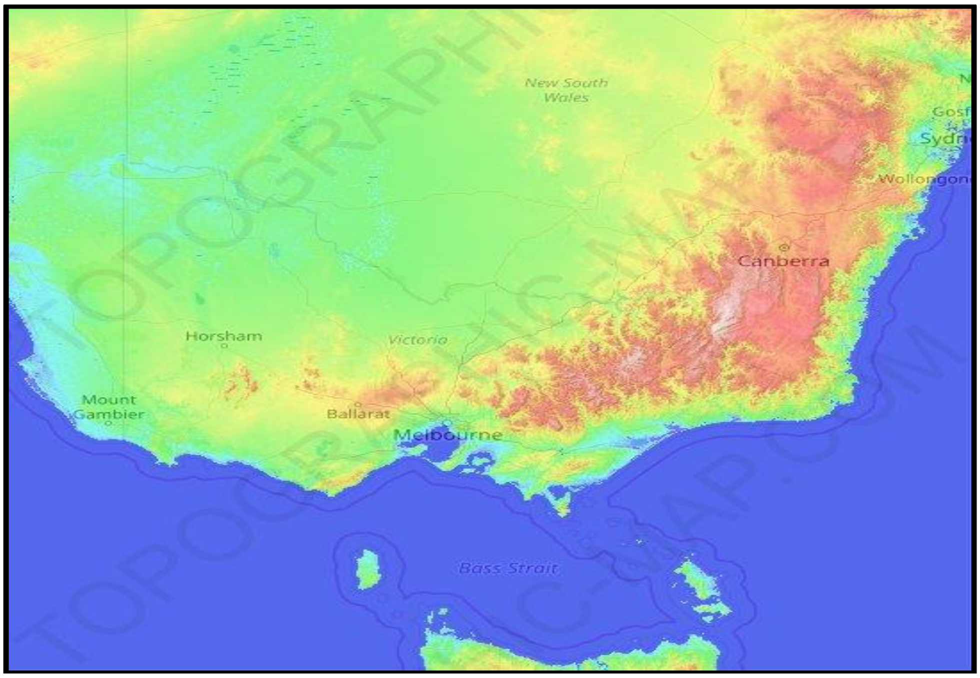


Figure 1.5 Victoria topographic map (Source: Topograhic-map.com, 2012)

1.6 Chapter layout

Table 1.1 Chapter layout

CHAPTER	CHAPTER TITLE	CHAPTER CONTENT OVERVIEW
1.	The orientation of the study	The chapter gives an overview of the study: Introduction, Background of the study, problem statement, aim and objectives, and description of the study area.
2.	Literature review	The chapter presents a theoretical literature review from the textbooks, journals, sources from the internet as well as empirical literature review on the hazard analysis, definitions, coping capacity, factors contributing to veldfires, preparedness, and application of the KBDI.
3.	Research methodology	The chapter presents a quantitative method for the KBDI model specification and estimation techniques on veldfires under the following headings: Introduction, Research approach (quantitative method), Data quality control, Population and sampling techniques, Data collection techniques, Data analysis, ethical consideration, and Summary.
4.	Analysis and interpretation of data	The chapter look at the empirical results in the study area starting from the pre-data analysis which provided an overview of the structure and characteristics of the input variables of KBDI.
5.	Summary, results, conclusion and recommendations for future research	The chapter gives a summary of the study, results, conclusion and recommendations. The conclusion is made based on the quantitative observations performed and the literature review carried out. The results were summarised according to the study's objectives.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

Essentially, a literature review describes articles and synthesizes the literature applicable to a particular area of research. It illustrates how knowledge has grown in the field, highlighting what has already been accomplished, what is widely received, what is emerging and what is the new thoughton the subject (Bloomberg and Volpe, 2012). Also, a literature review identifies a gap in a study (for example undiscovered or under-researched areas) and expresses how this gap is addressed by a particular research project (Kimberley and Crosling, 2012). The sections covered by this segment comprise the definition of terms relating to the study, causes and impact of veldfires, the correlation between climate and veldfires, veldfires risk analysis and hazard analysis, elements that are exposed and vulnerable to veldfires, Victoria veldfires scenario and coping capacities, prediction of veldfires' intensity using the KBDI, veldfires' management policies and regulations, a conceptual model of risk and vulnerability (BBC framework), and BBC framework application to the research area.

2.2 Definitions of terms

2.2.1 Veldfires

Veldfires are characterized as any unplanned wildland outrage that, irrespective of the source of ignition, may involve a response to suppression, or acts according to agency policy (Regos et al, 2014). Depending on the local custom and the wood being burned, various words are used apart from veldfire: Examples include wildfires, bushfires, forest fires, and grass fires. Whatever veldfires are called, these terms refer to only one thing (Food and Agricultural Organisation of the United Nations [FAO], 1986). Australia is no stranger to veldfires, and the 2019–2020 season has in many respects proven to be unparalleled. The first major veldfires started in June, just before the official start of spring, and then new out-of-control fires erupted early in September 2019. The fire situation deteriorated significantly in early November 2019. A surge of rainstorms eventually brought relief in some areas affected by veldfires in mid-January 2020 but was nowhere near adequate to extinguish the fires (Centre for Disaster Philanthropy, 2019).

2.2.2 Climate

Climate change is a long-term shift in temperature and weather patterns typical of a region. Climate change may refer to a specific location or the entire world, it may lead to less reliable weather patterns (Denchak, 2017). In Australia, the erratic weather patterns made it difficult to sustain and grow crops in regions that relied on agriculture, as predicted temperature and precipitation patterns can no longer be depended on (Pryor et al 2014). Climate change has also been connected with other destructive weather events such as more frequent and more intense hurricanes, flooding, heavy rains, and severe thunderstorms (Union of Concerned Scientists, 2018).

2.2.3 Forest management

Forest management is the system of planning and implementing forest management planning and implementation, and uses activities to achieve particular ecological, economic, social, and cultural objectives (Liberia. Forestry Development Authority [FDA], 2009). It addresses the financial, cultural, legal, social, technological, and scientific aspects of natural and planted forest management. This can entail varying degrees of deliberate human activity, ranging from activities aimed at safeguarding and preserving forest habitats and their functions to those promoting particular species of social or economic interest for enhancing forest products and services development (Rainforest Alliance, 2017).

2.2.4 Hazard

A hazard may be a possibly dangerous physical occurrence, social and economic disturbance or damage to the environment. Typical hazard examples may be the complete absence of rain (leading to drought) or its abundance (leading to flooding). Chemical processing plants and incorrect agricultural practices in the vicinity of communities can also be seen as risks that could contribute to emergencies. Hazards may be man-made or naturally created (Wisner et al. 2003). In 2019 two Australian states declared a state of emergency as bushfires brought a ‘catastrophic’ danger to the east of the nation’s densely populated regions (BBC News, 2019)

2.2.5 Vulnerability

Vulnerability can be seen as a person’s or group’s failure to anticipate, cope with, or avoid the consequences of hazard or disaster or to recover. Marginalized, poorer, and overcrowded communities are more vulnerable and less capable of handling disasters (Wisner et al. 2003).

The Australian Black Saturday bushfires of 2009 were a devastating example of the vulnerability and the danger faced by many communities in case of a large-scale uncontrolled wildfire (Aurecon, 2012).

2.2.6 Coping capacity

'Ability to cope' is viewed as a collection of all available resources and capabilities within a community or entity that can lower the risk level or the impact of a disaster. Many studies often consider it as one of the main elements of 'vulnerability' (Hoffman and Blecha, 2020). Across the globe, natural disaster management strategy is gradually associated with resilience ideas. The National Disaster Resilience Plan describes how Australia will strive to enhance social and community resilience, with the assumption that resilient societies are in a far stronger place to survive the trauma and recover from traumatic disasters faster than ever (Parsons et al. 2016).

2.2.7 Keetch-Byram Drought Index

The KBDI assesses the fire risk by illustrating the net effect of evapotranspiration and rainfall in deep duff and top-soil surfaces containing accumulated moisture deficiencies. The index ranges from zero, the point where there is no deficiency in humidity, to 800, the highest potential to drought (National Integrated Drought Information System, 2017). The content of soil moisture determines the level of drought that affects vegetation and organic material in the upper layer of mineral soils and the whole profile of organic soils. The KBDI provides a guide to Australian fire managers on the flammability of organic material on and inside the soil surface which can impact their ability to suppress bushfires (Western Australia. Australia. Department of Fire and Emergency Service [DEFS], 2014)

2.2.8 Preparedness

Preparedness leads to the reduction of disaster risk by steps taken beforehand to ensure an efficient and effective approach to the effects of disasters, including prompt and reliable early warnings and the immediate resettlement of communities and properties from endangered regions (UNDDR, 2009). Preparedness helps government departments and other entities engaged in disaster risk reduction, the corporate industry, and communities to prepare, coordinate, and provide recovery measures to cope with an imminent or existing disaster or disaster impact. Preparedness differs from prevention and mitigation, as it emphasises the practices and steps taken before a potential hazard or emergency (United Nations office for

Disaster Risk Reduction [UNDDR], 2009). Following Australia's 2009 bushfire crisis the drought volunteers and subsistence farmers were trained to prepare for any potential bushfires, and communities in the Victoria State were encouraged to heed early warning systems as a measure to prepare for wildfire impact (DFES, 2020).

2.2.9 Disaster mitigation

Mitigation is described as the way to minimise disaster's adverse repercussions or impacts (United Nations International Strategy for Disaster Reduction [UNISDR], 2004). These initiatives can target the hazard or the threat itself, for example, positioning firebreaks on the interface between urban and wildlands. It is also called the 'structural mitigation', as proper buildings or engineering steps are needed to take the danger away from the vulnerable people (United States Agency for International Development [USAID], 2011). As the damage from Australia's bushfires was growing, the insurance industry called for concerted action to reduce the impact of climate change (Cadman, 2020).

2.2.10 Response to disasters

Disaster response means to assist or to intervene on those affected at the time or shortly after a disaster to meet the life protection and survival needs. It can be of immediate, short, or prolonged length (National Research Council, 2006). During the 2019 Australian bushfires Red Cross teams and other NGOs assisted people in five evacuation centres and offered assistance and information at nine disaster care points for residents. They also supported people in the most affected communities who faced language barriers and undertook needs assessments. Through Register, they managed to register over 18 850 people (American Red Cross, 2020).

2.2.11 Resilience

This refers to the ability of a hazard-exposed device or group to avoid, recover, tolerate, and absorb adverse hazard effects in a timely and successful manner (UNISDR, 2004). It is important to remember that a resilience initiative that targets high-risk locations using suitable infrastructure, policy, and procedure combinations have the potential to bring economic benefits. Geoscience Australia Flood knowledge upgrades were allocated a $12 million budget for 2016, equivalent to $3 million per year. The Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) earned over eight years a budget of $47 million, equivalent to $5.9 million a year. Victoria's Bushfire Risk Map initiative got $13.8 million (BNHCRC 2019).

2.3 Causes and impact of veldfires

The bulk of the world's veldfires are man-made. Human-caused fires result from camping fires left burning, debris burning, equipment usage and malfunctions, cigarettes negligently discarded, and deliberate incendiary actions. Veldfires can also be caused by nature such as lightning. There are two forms of lightning, namely, cold flash and hot flash. Cold lightning is a return stroke with an intense, but relatively short-lived electrical current. Hot lightning has lower voltage currents but these occur over a longer period. Fires are typically ignited by hot lightning bolts that are exceptionally long-lasting (Feng and Liang, 2019).

Veldfires destroy around 14 million hectares of fire-prone forests globally each year, a level of destruction and depletion equivalent to that of destructive deforestation and agricultural conversion (Butler, 2019). At the same time, many forest habitats that are adapted to fire are becoming heat-starved. Human beings, including government agencies responsible for forest resource management, are altering natural fire regimes around the globe without taking into consideration the long-term implications. (Ganz and Fisher, 2003) in their article believe policy-makers and the public are best positioned to respond to repeated short-term problems rather than to concentrate attention on long-term, sustainable solutions. Resources need to be redirected to promote work that enhances knowledge of fire causes, recognizes existing management practices that encourage hazardous fires and foster management structures that emulate natural fire regimes or make the most of the well-known fuel usage.

In most cases dealing with fires was interpreted as fighting fires or adding fire-fighting power, but that method does not work. The communications sent to politicians and communities also provide a very clear picture of a complicated situation. Not all the following issues regarding fires are real: (i) Extreme weather triggers veldfires; (ii) all veldfires are toxic (iii) every fire should be stopped and extinguished; and (iv) veldfires are mostly concerned with regular occurrences as they happen (Feng et al. 2019).

Explanations that are unnecessarily simplistic about veldfire theories continue to allow law-makers to take the view that fire suppression is the primary remedy for dangerous veldfires. To date, the insufficient focus has been devoted to tackling underlying causes and attempting to prevent a spiralling downward trend of repeated flames and degradation in burnt locations.

2.3.1 International case studies on veldfires

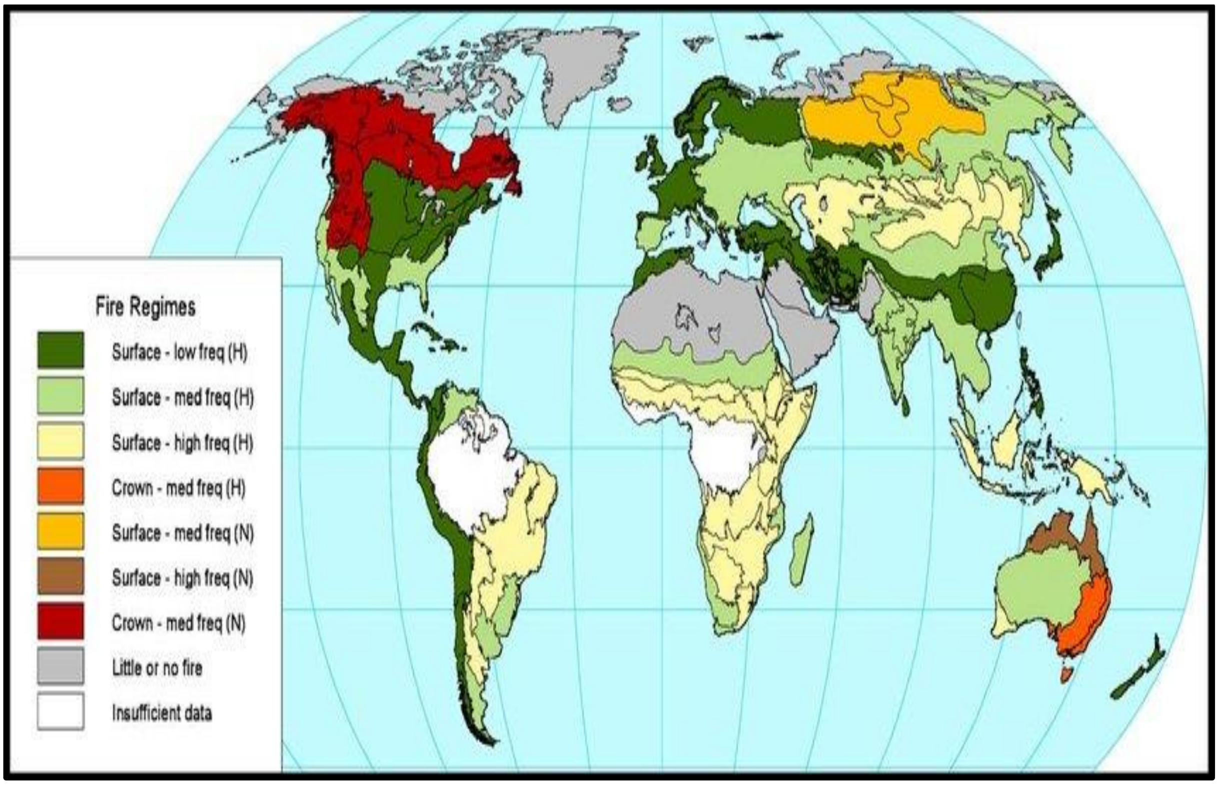


Figure 2.1 World Fire Regime map. (Source: Food and Agriculture Organization of the United Nations 2020)

The map in Figure 2.1 shows the principal causes, the form of veldfires, and size of veldfires. This map is an estimation provided that fire statistics are limited for certain regions (Stocks et al. 2003). There is a distinction between natural or human-induced causes (in the story, N or H), ground fire forms and crown fire. Low frequency means a period of fire over 200 years, medium frequency over 20 to 200 years, and a high frequency over less than 20 years (Bowman et al. 2011).

2.3.1.1 The role of fire in the management of ecosystems

The National Research Council (2011) in their study found that eco-regions worldwide rely on or are affected by heavy fire. Veldfires in these regions are as important to the protection of human flora and fauna, as rain and sunlight. Typical fire ecosystems include the taiga, African grasslands, South Asian rainy season and dry forests, Australia’s eucalyptus forests, California’s coniferous forests, the Mediterranean region, and all pine forests from taiga to subtropics. All these habitats formed with fire. Fire frequency and intensity depend on natural variables such as climate, the form of vegetation, lightning strike, and accumulated biomass or land. Burns retains the characteristic ecosystem structure and composition that has evolved with fire. All these habitats do not burn in the same way, though. For example, low-intensity ground fires are common and required in many forests, grasslands, savannahs and wetlands to preserve an open landscape with a multitude of grasses and shrubs (FAO, 1998). Certain forest and bushland habitats depend on uncommon, but extreme, fires that rejuvenate the system. What sets all fire-dependent ecosystems apart, however, is the resilience of the plant and animal populations and capacity to recover, provided that the fire stays within the limits imposed by natural factors. Fire prevention can deliver far-reaching environmental benefits and socially unwanted ecosystem changes. For example, full fire prevention has caused thatthe traditional grass scenery of some parts of the southwest United states, offering food for both wildlife and cattle, turn into thick pine woods with little grass growth, providing fuel for fires that are extremely dangerous and damaging (Hirschberger, 2016).

2.3.1.2 Veldfires and the changing climate

Figure 2.2 Picture depicting how smoke affects the climate (Source: Perry, 2020)

Veldfires contribute to climate change significantly by causing the release of greenhouse gases (Figure 2.2). The warmer climate contributes to dryer and damaged forests, which makes them more vulnerable to flames. A rise in the number and intensity of fires generate a positive feedback loop (Melillo et al. 2014). In the study by Hirschberger (2016), he found that savannah and veldfires release 1.6 to 4.1 billion tons of carbon atmospheric dioxide per year; additionally, approximately 38 million tons of methane ($CH4_2$; 1 t $CH4_4$ = 21 t CO_2) and 21 million tons of carbon dioxide, nitrogen oxides (NOx) and 3.5 million tons of sulfur dioxide (SO_2) are released every year. It attributes to 15% of global greenhouse gas emissions. Most are caused by clearing fires in tropical rainforests and the subsequent land conversion. Veldfires are responsible for 33% of the world's carbon monoxide and 10% of methane emissions, as well as more than 86% of soot.

Several studies suggest that climate change will increase the number of hot and dry days with elevated fire risks, extend fire seasons, and increase electrical storm frequency. This will increase the incidence of veldfires and will affect the forest regions.

2.3.1.3 The situation surrounding veldfires in the six geographic regions

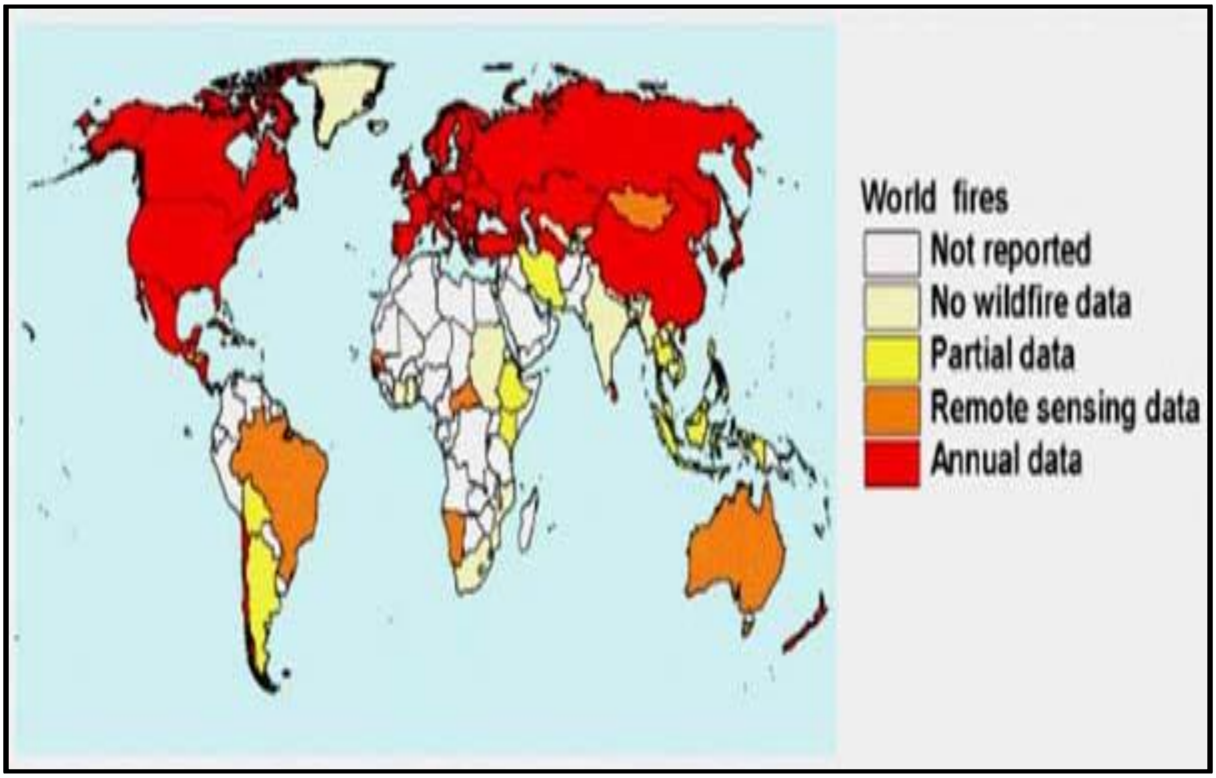


Figure 2.3 Global veldfire data (Source: FAO, 2001)

Above is a map showing the availability of world fire data based on the united Nations Economic Commission for Europe data and data submitted by countries to the Global Fire Assessment (FAO, 2001). This study looked at the fire situation in the six geographical regions-Africa, Asia, Europe, Oceania, North and Central America, and the Caribbean and South America. The following segment presents perspectives on fire safety from the six regions.

- **Asia**

In the 1990s the Asian region experienced severe outbreaks of wildfire and smoke (Doerr and Santin, 2016). In the study by the FAO (2001), the insular region was found to be the most affected by most events in the 1990s during the El Niño-Southern Oscillation particularly during the 1997–1998 intense El Niño-Southern Oscillation. Extended droughts favoured land-use fires, burning forest regeneration, and increasing wildfire situations. The fires have triggered loss or degradation over large areas of primary and secondary rainforest habitats (Butler, 2012). Indonesia has been the key source of smoke-haze, impacting the entire region for almost a year and affecting the health of more than 100 million people in the country (Aiken, 2010).

- **Europe**

Fire poses the most significant environmental threat to forests and wooded areas of the Mediterranean basin. It is destroying far more trees than any other natural calamity: pest attacks, insects, strong winds, cold, etc. (FAO, 2001). Certain countries in the Mediterranean are experiencing relatively long dry seasons, On the coasts of France and Italy, it lasts between one and three months. In the northern parts of the Mediterranean, on the coasts of Libya and Egypt in the south, it may last more than seven months (Alexandrian et al. 1998). In the Russian Federation, the 1999 and 2000 fire seasons were less serious than in 1998, when fire affected 4.28 million hectares of forest and other fire-protected areas. The region burnt in 1999 was 752 000 hectares, and up to September 2000, 1.14 million hectares were burnt (FAO, 2001).

- **Africa**

Due to the regular and widespread occurrence of veldfires, Africa is often referred to as the ‘fire continent’. This definition is equally true in southern, western and eastern parts of Africa where the savannah biome is a major plant community (Larsen, 2009). Komarek (1968), in his study, mentioned that Africa is extremely susceptible to lightning storms and has a dry, wet-season fire climate in which fires consume the fuels created and stored during the rainfall period. While lightning was the principal cause of fire ignition in the African savannahs in the past, the situation today is one in which humans have become more prominent as a source of ignition, than lightning. Africa has the world’s largest tropical savannah fields and during the dry season, the grassland becomes flammable (FAO, 2001).

- **North and Central America and the Caribbean**

The United States and Canada cover 18.8 million km^2, around 14% of the world's land area. Both share one of the longest common borders in the world, providing numerous opportunities for transboundary fire protection cooperation (Plecher, 2019). Mexico's area of land is around 141.7 million hectares, of which 57.8 million hectares are temperate and tropical forests and 59.4 million hectares are arid and semi-arid areas. Mexico's common border with the United States is approximately 3 300 km long and offers many opportunities for international cooperation during veldfires (FAO, 2016). An Earth Policy Institute, (2009) study found that in the west of the United States, Mexico and Central America in 2000, extreme drought conditions have resulted in veldfires damaging approximately 2.6 million hectares of forests and grasslands. This indicates that the frequency of fires is largely associated with conventional burning for land clearing and livestock. Firefighters are frustrated by the veldfires during the dry season.

- **South America**

Fire as a resource for land use is strongly rooted in the culture, society and traditions of most of the region. Fire was used to prepare for planting crops or grazing fields, clearing inaccessible lands for sustainable farming, promoting hunting, or maintaining a clear countryside. (Kanianska, 2016). Continued use of fire in land-use practices, increasing population, and a decrease in the financial situation of many people in the area are prime causes of rising veldfire problems. Determining the actual size of the issue is challenging. In certain cases, fire reports are non-existent, unreliable, or deceptive (Hirschberger, 2016). The FAO (2001) argues that there is no shared concept or description of what constitutes veldfire. An analysis of the statistics available indicates that 50-95% of a veldfires that starts in these areas is the result of controlled farmland burns or land clearing burns. For years, so much agricultural burning has occurred, that the large amount of smoke does not cause any fear anymore. Satellite imagery cannot make a distinction between unmanaged and unregulated wildfires and controlled burns. In the early months of 1998, satellite imagery increased government and international awareness of the vast number of 'hot spots' in the region. Fire activity was severe in the Deep South during the 1997–1998 fire season, affecting the central part of the country in 1998–1999. The latter year was the worst veldfire year in the history of Chile, with 6 830 fires and 101 691 hectares destroyed. The

‘La Rufina’ veldfires destroyed 25 400 hectares, 14 homes, livestock, and electricity lines (United Nations Office for Outer Space Affairs [UN- SPIDER], 2009)

- **Oceania**

Australia, a continent vulnerable to fire with a wide variety of vegetation and fire regimes, dominates the Oceania region (Russell-Smith and Yates, 2007). Fire plays a significant role in most aspects of vegetation’s ecosystems, and humans too have had to deal with it and learn to manage it. Much of Australia’s vegetation patterns are flame-adapted and many are fire-dependent for regeneration (Adams, 2013). Most Australian veldfires are accidentally or deliberately ignited by people, while lightning is significant, particularly in rural areas. During the fire seasons of 1998–1999 and 1999–2000, 116 000 and 231 000 fires were recorded per year by remote satellite sensing, respectively. After the end of the El Niño drought in 1997–1998, fire activity in Australia and New Zealand returned to normal again. New Zealand fire statistics show that a total of 6 320 hectares of forests were burnt annually between 1989 and 1999 (FAO, 2001).

2.3.1.4 Veldfire statistics

Table 2.1 Veldfire statistics of the countries of the world

Type of fire (veldfires) of the countries of the world 2012–2016				Average number of deaths per year 2012–2016		
Country	***Inhabitants***	***Im Wald***	***%***	***Year***	***100000 in h***	***100 fires***
USA	323128	–	–	3244	1.0	0.2
Russia	146270	11025	7.3	10109	6.9	6.7
France	66628	51941	18.2317	317	0.5	0.1
Ukraine	42673	1279	1.7	2262	5.3	3.2
Romania	20121	133	0.5	375	1.9	1.2
Czech	10579	892	5.5	118	1.1	0.6
Hungary	9830	–	–	114	1.2	0.5
Austria	8740	438	1.0	25	0.3	0.1
Israel	8300	–	–	19	0.2	0.2
Bulgaria	7245	511	1.4	93	1.3	0.3

Source: Centre of Fire Statistics (2018)

The fire and death statistics for 2016 are based on data from ten countries in the world that have provided data for one or more of the five years in 2012–2016 (Centre of Fire Statistics, 2018).

2.3.2 National (Australia)

Veldfires make up an integral part of the Australian climate. Natural ecosystems have evolved with fire, and the landscape and its biodiversity have been changed by both historical and recent fires. Most of Australia’s indigenous plants are not fire-resistant and highly flammable, while other organisms rely on fire for regeneration (Munroe and Taylor, 2020). Fire has long been used by indigenous Australians as a method for land management, and it remains to be used to clear land for agricultural purposes and to protect property from extreme, uncontrolled fires. Ultimately, veldfires causes many casualties and significant damage to the land. Although natural veldfires cannot be prevented, their effects can be minimised through the implementation of mitigation measures and the possible effects on the most vulnerable areas (Bowman, 2008).

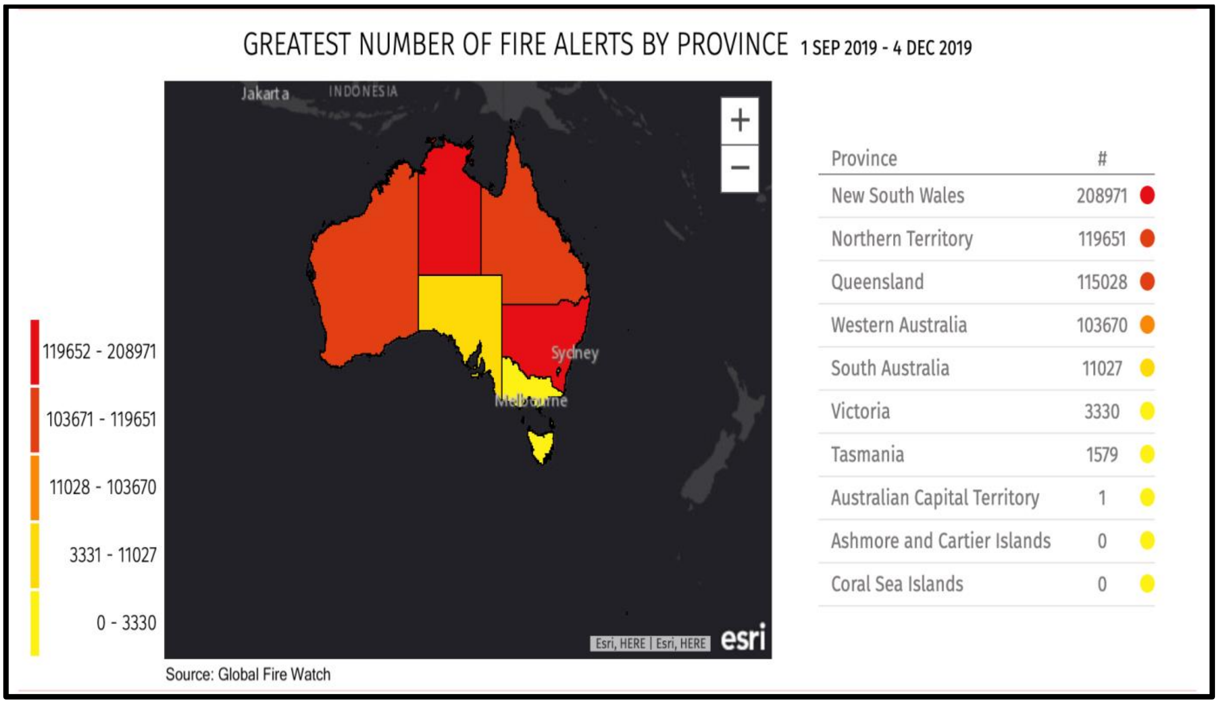


Figure 2.4 Fire alerts by states in Australia (Source: Fire Watch Australia, 2020)

2.3.2.1 Areas with frequent veldfires occurrences

The Government of Australia reported in 2013 that the temperature is hot, dry and drought-prone. At any time of year, certain parts of Australia are vulnerable to veldfires. The widely varying fire seasons are reflected in the continent’s varied weather conditions. The time of danger to much of the south of Australia is summer and autumn (Geoscience Australia, 2013). The biggest threat usually occurs during spring and early summer for New South Wales and southern Queensland. The Northern Territory experiences the bulk of its fires in winter and spring. Grassland fires frequently occur after good rainfall periods which leads to overgrowth that dries out during extreme heat (The Guardian, 2019). If such extreme fire weather is experienced in the vicinity of populated areas, big losses are probable. With regards to the total areas burnt, the main fires are in the Northern Territory and northern parts of Western Australia and Queensland. Most life losses and financial harm occur in the outskirts of cities where residences are next to combustible vegetation (Nolan and Thornton, 2016).

2.3.2.2 Factors creating a favourable environment for the occurrence of veldfires

The basic factors that determine whether a veldfire can occur include fuel supply, oxygen and an ignition source.

- **Fuel load**

Fuel load describes the volume of fallen trees, leaf litter and tiny branches that accumulate in rural areas. In general terms, the higher the load of fuel, the hotter and the stronger the fire is. The concentrated yet poorly compressed fuel would burn faster than highly compacted or distributed fuel sources (Buckingham et al. 2015). In Bakley's (2006) study of assessing and managing forestland after a wildfire, it was found that smaller pieces of fuel, such as twigs, leaf litters, and branches, burn quickly, particularly when they are dry. Bigger pieces of fuels such as tree stumps often burn later after the front of the fire has passed through. Natural oil inside eucalyptus trees stimulates the combustion of fuel (Barkley 2006).

- **Angle to the slope**

Fires make use of radiation and convection to preheat their source of fuel. As a result, flames intensify and decelerate downhill travel while going uphill. Slope steepness plays an important part in spreading fire intensity. The speed with which a fire front advances will double for every 10 degrees in the slope so that on a 20-degree slope the advance speed is 4-four times higher than on level ground (National Wildfire Coordinating Group 2016)

- **The source of the ignition**

According to the analysis of the Commonwealth Scientific and Industrial Research Orgnisation (CSIRO, 2009), it has been recorded that veldfires can result from both human-induced and natural causes, with lightning as the leading natural source, accounting for about half of all Australian ignitions. The remainder is accounted for by fires of human origin, marked as accidental or deliberate. Fires that are deliberately lit may be the result of arson or may be designed to achieve a beneficial result, but then conditions have changed, leading to uncontrollable spread (CSIRO, 2009). Unfortunately, deliberate and accidentally sparked fires are more prevalent near populated areas and have a higher likelihood of impacting on infrastructure. Arsonists create serious and needless risks to humans and resources, particularly when igniting fires during days of extreme fire risk.

- **Moisture in the fuel**

Dry fuel burns easily, and muddy or wet fuel does not burn. Consequently, the period after rainfall and the amount of rain that has been received is a significant factor when determining the risk of veldfires. A calculation of the drought factor, or moisture deficit, is often used as an indicator of extreme veldfire weather conditions (National Fire Coordinating Group, 2016).

2.3.2.3 Consequences of veldfires in Australia

Over 1 000 residences have been burnt, and more than 200 people have died since the fires started in September 2019. Owing to smoke, Queensland and New South Wales suffered air pollution that caused many people to seek emergency assistance on respiratory problems (Hughes et al. 2020). The Greenhouse Office of the Australian government found in 2003 that the air quality in Sydney was reported 11 times the ‘hazardous’ level. The Australian government has faced a lot of criticism particularly due to the obvious impacts of the fires due to lack of action and policy reform for climate change. New South Wales has been hit hardest with more than 3.7 million hectares of land burnt and more than 5.8 million hectares over the whole country (Pittock, 2003). The Guardian (2020) stated in their article that while Australia had fires of this scale before, they were by no means the norm. In 1974 and 1984, they encountered bigger fires in New South Wales, although the fires in 2020 were far more serious. Areas where the fires were burning recorded the lowest rainfall from January to August 2019. Areas that had never burned or occasionally burned before were charred, too. Such areas include the rainforests, swamps and wet eucalyptus forests (Rueb, 2020).

The impact of the veldfires on wildlife has caused it to get much attention. As many as 1 billion animals were killed in the fires. Animals have their defence system when it comes to natural disasters, but the past fires and deforestation have eliminated the tools once used. The devastating impact that the veldfires have had on the koala population was noticeable. For example, they are not fast moving animals which don’t allow them to escape from the fires quickly enough (Rueb, 2020). The koala’s form of defence is to crawl up to the treetops and curl into a ball where it waits for danger to pass. Even though they have adapted and evolved together with veldfires, deforestation from human activities and climate change impact the koalas’ ability to survive. It is estimated that as many as 8 000 koalas have died from the current veldfires, and the lack of eucalyptus trees and water supplies will continue to affect them until the fires stop. Around 30% of its primary habitat has been lost (Kenyon, 2019).

The koalas aren't the only animals which suffered. While many animals, such as kangaroos and birds, may flee the fires, fleeing sometimes poses a danger to these animals, for example being hit by cars or even being attached by dogs. A lack of water also poses danger. Temperatures reached a record high of 106ºF causing thousands of flying fox bats to fall from the sky and wiping out about one-third of that particular population. Temperatures and fires are so far removed from the natural that normal wildlife adaptations no longer function (Bittel, 2019). From the above, it can be deduced that Australia relies on short-term solutions rather than on finding a lasting solution to disaster response, which in turn will contribute to social growth through the creation of jobs and other sustainable development economic activities such as countries like the United States.

2.4 The correlation between climate and veldfires

Climate plays a significant part in the creation, development, and death of a veldfire. Drought contributes to absolutely disastrous veldfire situations, and winds aid to the progress of wildfires – climate can drive the fire to travel faster and consume more ground. It can also make the battle against fire a lot harder. The atmosphere contains three ingredients which can cause veldfires: temperature, wind speed and precipitation (World Meteorelogical Organisation [WMO], 2018).

2.4.1 Temperatures

Temperature affects the sparking of veldfires as mentioned above because heat is one of the three components of the fire triangle. On the ground, the rocks, leaves, and underbrush receive direct heat from the sun that heats and dries up possible fuels. NASA (2019) released a report stating that warmer temperatures allow more rapid ignition and burning of fuels, adding to the pace at which a veldfire spreads. For that reason, when temperatures are at their hottest in the afternoons, veldfires appear to rage. The heat from the sun is transmitted by radiation onto the earth. This heat warms the earth’s surface, and the near-surface atmosphere is warmed up by the heat emanating from the air. That is the reason why the surface temperature is hotter than the surface of the earth. Typically, the temperature drops by an altitude of about 3.5 degrees per 304.8 meters. This decline is known as the adiabatic lapse rate (NASA, 2019).

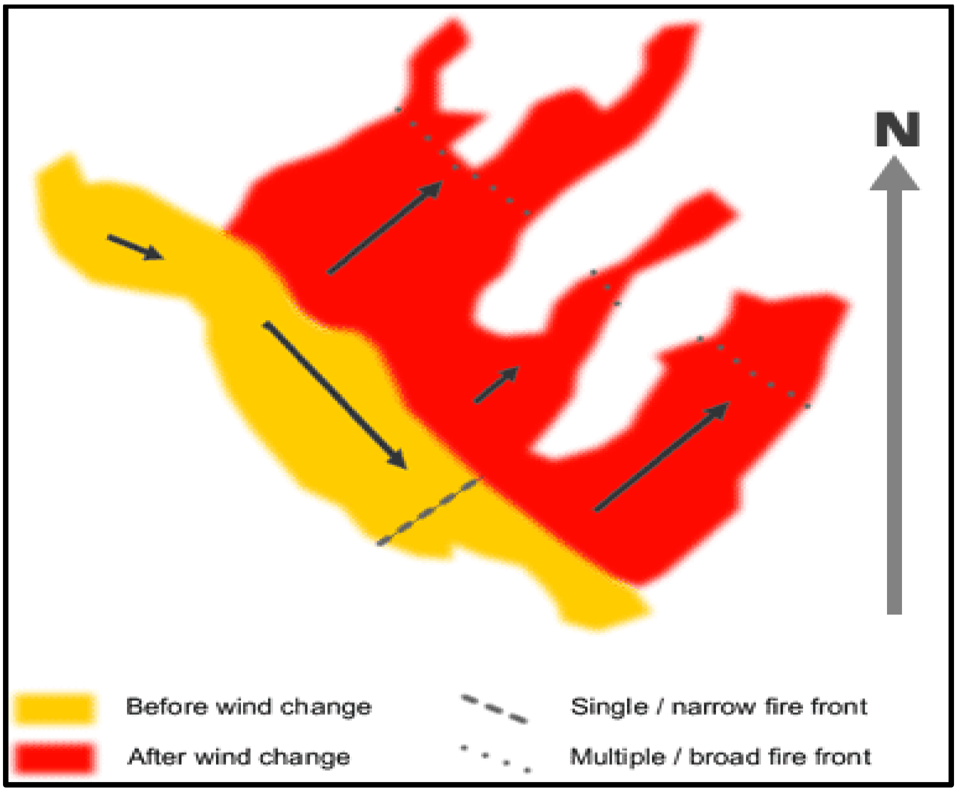


Figure 2.5 Weather affecting fire behaviour (Source: Bushfire CRC, 2020)

Forest fuels receive solar heat through radiation. Consequently, it takes less heat to ignite. Differential heating of the earth's surface is the driving force behind most atmospheric factors as shown in Figure 2.5. On short waves, the sun releases light rays (radiation). If a solid surface like trees or grass is hit it is heated. The atmosphere retains some of the heat and reflects some of it in long-wave radiation, which is absorbed by water vapour in the air and thus also raises its temperature (United States. National Weather Service [NWS], 2018). Temperature is potentially the single most important factor affecting fire behaviour. Some would say the most important factor is relative humidity, but we'll discover that relative humidity influences climate. Fuel temperatures also influence the rate at which a fire spreads. Hot fuels can combust and incinerate faster, as they need less excess heat to raise the burning rate of the fuels. Fuels that receive direct sunlight would be warmer in daylight than the combustibles. They are going to get drier too. For that reason, fuels not covered by trees will typically be warmer and drier, resulting in stronger flames. Fires burn fiercer in the afternoon. The temperature then is significantly higher leading to higher fuel levels. Therefore less heat is needed to bring the fuel to its ignition temperature. At the same time, rising temperatures cause a reduction in relative humidity and vapour (Auburn University, 2019).

Mugdal et al. (2014) reported that the surface layer, too, can influence the temperature. The temperature on the surface of a body of water will be higher because the heat will penetrate and disperse across the atmosphere. Bare soil, on the other hand, will be higher because sunlight does not penetrate. It will be concentrated on the surface, instead. Most of the sun's heat would be absorbed by the trees in the wooded areas. This is why fuel in the shade would be cooler than it is in the sun (Mugdal et al. 2014).

2.4.2 Wind speed

Wind possibly has the greatest effect on veldfire's behaviour. It also represents the most unpredictable factor. For the prescribed firefighter burners, the wind is important because of three characteristics it has on veldfire behaviour: (i) oxygen supply for the incineration process, (ii) reduction of fuel moisture through enhanced evaporation (iii) exerting pressure to physically transfer the fire and heat generated closer to the fuel in the fire path through radiation like pitching burning embers, firebrands in some cases (Auburn University, 2019).

Wind may be the most persistent problem. It can change acceleration, course, or it can become very ragged. Fire propagation rate and intensity are affected by wind. High winds will easily trigger the head of a fire to travel forward. It may cause the fire to crown the peak of the trees and leap barriers that normally stop a fire (Bushfire Foundation, 2020).

Wind's effect on vegetation:

- Friction reduces the movement beside the surface;
- Is responsible for turbulence and eddies;
- Fire at the edge of openings is more intense;
- It increases evaporation by discharging moist air next to the fuel.

Coen et al. (2020), senior scientists at the National Centre for Atmospheric Science, developed a computerised model which showed how winds travel on a small scale. Since 1991, they have modified the model to include veldfire features, such as fuel and the exchange of heat between flames and the climate.

Their research have found that not only does wind affect how the fire develops, but that fires themselves can develop wind patterns. They provided guidance on how the fire spreads as the fire produces its weather patterns. Winds, called fire whirls, can be created by massive, violent veldfires. Similar to tornadoes, fire whirls are the product of vortices produced by the fire's heat. You get whirls of fire if those vortices are tilted from horizontal to vertical. It has been recognized that fire whirls are caused by hurling burning logs and flaming debris over large distances. 'There's another way that you can tilt the vorticity. That is it can be titled without breaking into fire whirls, and be burst forward into what’s called hairpin vortices or forward bursts’ (Coen et al. 2020). ‘These are quite common in crown fires [fires at the top of trees], and so you see fires licking uphill sides.’ Forward explosions can be 20 m (66 ft) long, and blast out 100 m (328 ft) at a speed of 100 mph (161 km/h). Such bursts leave a scorched area, causing veldfires to spread (Coen et al. 2020).

The harder the wind blows, the faster the blaze erupts. The veldfire produces its own winds that are seven to ten times stronger than the normal wind. It may also launch ashes into the air and build extra flames, an activity called spotting. Wind can also alter the fire path, and gusts can raise the blaze into the trees, creating a crown fire (Bonsor, 2001).

2.4.3 Precipitation

The fire safety case study of Hamadeh et al (2016) found that the chance of igniting a veldfire is minimised by humidity, as moisture has a direct impact on fire suppression. Once the air becomes filled with moisture, humidity is released in the form of precipitation. Breeze and rainfall increase the amount of soil moisture that prevents potential veldfires. Rainfall influences the moisture and the relative humidity of the air instantly and directly. The temperature usually drops too, and the winds are cool. Usually, if more moisture is applied, precipitation happens when the atmosphere becomes humid. Precipitation will rapidly dampen the fuel surface to an extent that fires will not burn and veldfires will not occur. A significant factor in assessing the fire season (the moment when veldfires take place) is the rainfall pattern.

An experienced burn planner needs to know typical weather patterns in a district. The weather conditions are the product of pyrocumulonimbus cloud formation. They have been reported worldwide but as the global environment changes, they may become a more common phenomenon for Australians, the Environment Council of the country said in a 2019 report.

2.5 Veldfires and risk analysis

Scott et al. (2015) found that unplanned veldfires can have major, long-term impacts on ecological, social, and economic system. Thus, the risks presented by wildfires need to be recognized and quantified, and cost-effective mitigation strategies established afterwards. Morgan et al. (1990) assessed that risk assessment is a sophisticated analytical technique to risk quantification and acts as a method for promoting problem-solving that can guide financial, organisational, and tactical decision making. Risk analysis helps managers make decisions in situations where outcomes are potentially unpredictable

Olsen et al. (2017) examined that when we talk about the terms danger and threat we usually think about the potential for failure. This refers to wildfire threat and danger, but in comparison to most dangerous natural occurrences, wildfires can also offer significant environmental benefits. Therefore, the concepts of hazard and danger are extended in the study to consider the potential for fire-related losses. Veldfire risk is determined jointly by the probability and severity of wildfire. The risk analysis of veldfires is about finding solutions to some crucial issues: (i) How big can veldfires expand? (ii) Which components of veldfires are most at risk? (iii) What are the potential effects of fire on fragile elements at different intensity rates? (iv) Where can veldfires cause damage and where can they carry advantages? (v) What is the danger of wildfire spreading in rural areas? (vi) What places are more likely to suffer losses?

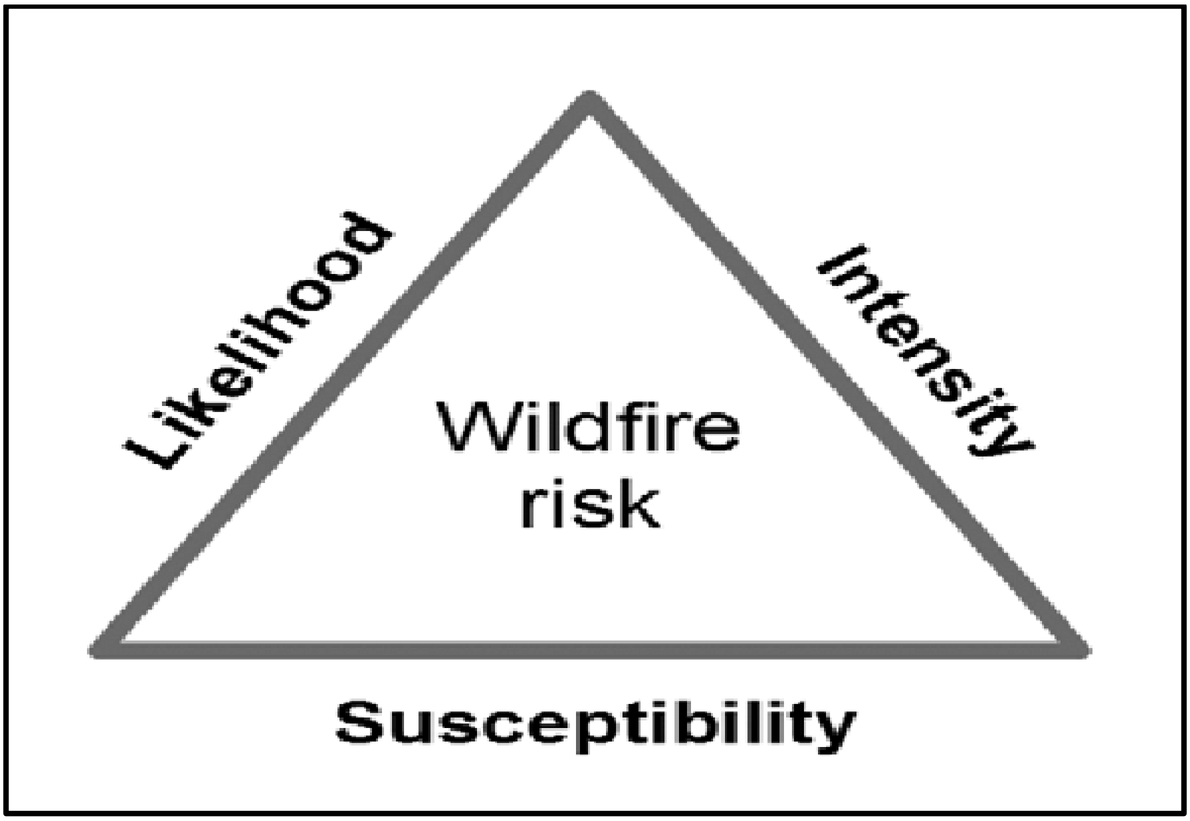


Figure 2.6 Hazard and Risk Principles (Source: Miller and Ager, 2012)

In the study of (Alan et al. (2010), it is mentioned that it is crucial to start with the comprehension of the definitions and principles used in hazard and risk assessment of veldfires. The words risk and hazard are not interchangeable but related. Risk is a physical situation which could harm hazard , vulnerabilty, and risk assessment (HVRA), with a (value) loss. In the context of wildfires, the definition of wildfire danger must be extended in the sense of veldfire to include the potential for beneficial improvements to the HVRA that partially or entirely compensate for any loss. In the analysis by Miller and Ager (2012), they found that the hazard classification usually refers to the physical characteristics of the natural occurrence, e.g. as the level of sea rise associated with coastal flooding, or the strength of continuous wind in a tropical storm, we use fire intensity measures, and flammability, as measurements of veldfire threat. Other metrics can also be useful, such as fuel usage or other fire elements.

Veldfire risk assessment also incorporates the possibility that if it does, an HVRA can experience an incident and the vulnerability of the HVRA (for example consequences for HVRAs caused by exposure to different levels of intensity). The vulnerability of a house to coastal tropical storms rests on the construction materials and design. Fire intensity is the primary characteristic of wildfires, usually correlated with future fire effects, but this is not always the case, the greater the intensity the greater the damage. Estimating risk includes estimating HVRA exposure to a dangerous phenomenon and the impact of that exposure on HVRA (Figure 2.5). Analysis of exposure examines the possible spatial associations of HVRAs with risk factors — the likelihood of fire and strength of fire — without considering how these factors influence HVRA performance.

2.5.1 Likelihood and strength of veldfires

Astudy by the United States Geological Survey (USGS, 2006) found that the possibility of veldfire danger is a physical condition with the ability for veldfire allowing HVRAs to have desirable or undesirable effects. The danger posed by veldfires can be defined as the occurrence of theveldfire itself, somewhat simplistically, but if it occurs, a more detailed characterisation often quantifies the potential intensity of the veldfire (probability distribution of intensity). Within the context of veldfire risk, it is also important to measure the probability of a veldfire occurring (in some fields, this is called the probability of dangerous occurrence), whether the overall likelihood of wildfire or the likelihood of veldfire occurring at a given level of fire intensity. The fire intensity level is strictly speaking independent from thelikelihood; they are different indicators. The report defines veldfire threat, in terms of both likelihood and severity, for our purposes. There are primary factors that drive the decision. Firstly, modern models of wildfire simulation co-estimate probability and severity, guided by a common collection of environmental factors. Secondly, as mentioned below, a useful way of characterising danger at a given location is often by a distribution of probability over veldfire severity rates. Location(s) spread parameters (heading, flanking, or back) under specific weather conditions, fuel moisture, and fire. Typically, this is evaluated as the near-maximum potential (e.g. fire heading under moisture and windy atmosphere of 97th percentile fuel) (USGS, 2006).

The analysis by Vaillant, Kolden and Smith (2016) found that veldfire occurrence and spread are simulated in a complete assessment of wildfire threat to describe how temporal weather variability and spatial fuel variability, topography, and ignition intensity affect wildfire risk across a landscape. Burn risk is also recorded on an annual basis for fire protection plan applications — the likelihood of burning during a single fire season. A distinctive element in the estimation of the annual likelihood of burning is the additional calculation of the likelihood of ignition and the period of the ignition. The relative rates of historical ignitions and their spatial patterns.

Additionally, Wu, Tsai and Chow (2018) in their book found some performance indicators reveal the probability of burning conditional on a fire that occurs throughout a specified weather condition called 'problem fire'. Veldfire incident management systems, on the other hand, reveal burn possibilities a fire over a matter of days or weeks. While some approaches to veldfire hazard characterization do not involve probability, modelling of fire probability plays a major role in characterising the capacity for effects of a veldfire, particularly where researchers are interested in modeling fire spread with variable combinations of place of ignition and climate conditions. In terms of probabilities, some veldfire modelling systems generate fire behaviour indicators, so the quantification of veldfire hazards will eventually have a probabilistic component. Summaries and maps of the overall probability of burning, the likelihood of burning by the degree of fire severity, mean severity of veldfire or flaming period are standard outputs of probabilistic hazard assessment. (for example, averaged across all simulations, integrating non-heading spread path and the estimated value of the intensity / length of the wildfire determined as the sum-product of the likelihood of burning and the mean intensity / length of the veldfire (Wu et al, 2018).

2.5.2 Analysing exposure

In the study of Thompson et al. (2013) it was found that the next critical move in evaluating wilfire is after the characterisation of wildfire threat. Risk: can be defined as an examination of exposure and the assessment of wildfire exposure. It refers to determining the severity of wildfire, and the possibility of burning at places where there are HVRAs. Therefore, this analytical step is focused on the capacity to reliably map all HVRAs over the whole spatial scope of the study. Exposure can be quantified in many ways, including the summary of statistics over mapped HVRA pixels such as estimated area burned. It can also mean the likelihood of burning or mean fire intensity. Exposure assessment of wildfires has wide applicability in forest planning. Rooke (2013) stated observers can make use of Rapid Assessment of Values at Risk maps that assess exposure from a veldfire incident that is on-going. In the United States National Environmental Policy Act [NEPA] assessments and the analysis of exposure may also be used to analyse the differences in exposure to HVRAs under various alternatives. The United States National Forest Management Act [NFMA] can also be used to research Forest Plan projects to identify HVRAs that are most likely to deal with veldfires and where such veldfires are most likely to occur in the countryside. Revising fire safety plans and assessing the possibility of remote ignition in different fire control circumstances involving complex HVRAs are some potential uses. (Hall, Scott and Gössling 2013).

2.5.3 Effects assessment

The study of Venn and Calkin (2011) found the next stage in the evaluation stages is the definition of how veldfire affects HVRAs. Predicting and quantifying fire effects, particularly for many environmental and other non-economic HVRAs, can be very complex and challenging. Fire impacts differenctly across spatial and temporal scales, and those impacts are affected by potential threats or other unpredictable processes. Restricted or incomplete scientific findings, a lack of statistical models, and discrepancies in the science of core fire and fire effects question fire forecasting. Nevertheless, estimating the response of HVRA to veldfires is a crucial step in quantitative risk assessment and prioritising mitigation efforts.

Reinhardt and Dickinson (2010) found in their study that the susceptibility of HVRAs to different fire intensity rates is based on a mixture of fire impact modelling and professional opinion. Despite the existence of first-order fire effect models (e.g. tree destruction, soil warming, fuel consumption and air pollution), there is still a need for some degree of analysis to explain second-order effects (e.g. solid waste, habitat destruction) in which authorities are usually more concerned. In some situations, fire effect models can exist for a specific HVRA. Mostly, substitutes, or relying on professional opinion may be needed. Fire impact analysis captures all fire-related gains and losses and is quantified in terms of value change, expressed in relative terms on a percentage basis (e.g., total loss = -100%). In this sense, 'response functions' translate into fire impacts and changes in value, based on fire intensity and possibly other ecological characteristics. A clear measure of veldfire risk across the economic and non-economic HVRAs is provided by such responses (Reinhardt and Dickinson, 2010).

2.6 Elements that are exposed and vulnerable to veldfires

Veldfires are unregulated fires that occur in woods and vegetated areas, which can spread quickly and are hard to manage. The changing climate due to global warming and droughts increases veldfire duration and intensity (Center for Climate and Energy Solutions, 2020). The study by the American Lung Association (2016) found that the consequences of increased veldfires would not only directly impact residents in veldfire-prone areas, but may also impact residents hundreds of kilometres downwind by smoke inhalation. The composition of veldfire smoke consists predominantly of carbon dioxide, water vapour, carbon monoxide, hydrocarbons, particulate matter, other organic compounds, nitrogen oxides, and many other trace elements. However, depending on the fuel type, heat and wind conditions, the content of the smoke can differ. Particulate matter is the most harmful of these toxins, considering their comparatively small size and ability to be inhaled deep into the lungs.

Some of the most vulnerable groups to smoke from veldfires are infants, people with heart or lung disease, and the elderly. Children are more likely to become compromised by smoke inhalation due to their weak airways and increased exposure from spending more time outdoors. In those with proven chronic heart disease and asthma conditions, such as the aged, finer and very small particles contained in smoke have been related to premature death. Guidotti and Clough (1992) found in their analysis that in addition to vulnerable people, firefighters face many occupational hazards. Rescue workers are vulnerable to dramatically higher concentrations and extended periods of particulate matter associated with fire, leading to health risks like diminished lung function, asthma, and respiratory and cardiovascular problems, as well as cuts and bruises caused by physical burns and falling trees. Fire overruns, hyperthermia, vehicle-related accidents (including aeroplanes), physical wounds and exposure to smoke and toxins and other air contaminants are some particular fire-line occupational risks. Veldfires can also increase the pressure on hospitals and primary health care services. Veldfires near inhabited areas, for example, often cause significant relocations, requiring the establishment of shelters, and care of people for burns, lung problems, and psychological health impacts. Over the past couple of years, increased residential development in or near the wildland-urban interface has risen, placing a greater number of people at risk. The vulnerability of communities to veldfires increases as these growth patterns continue, while climate change continues to deteriorate.

In 2015, Lake County, California recorded the third worst catastrophe, the Valley fire. (Chiu et al. 2015). Five years of severe drought contributed to that fire. In 24 hours 50 000 acres had been burnt. A large fuel load was built up and combined with the factors of drought and wind conditions, it helped to speed up the propagation. Many houses are built up in slopes and hills with limited entry and exits. Individuals with mobility disorders are particularly vulnerable. Without their vehicles or funds to buy petrol, they might not be able to evacuate. Many people with limited mobility, such as the aged including those in home-care, are also at risk of having trouble getting out of their burning quarters in hill fires. People were caught in traffic with fires raging everywhere. If people can't move fast or are unable to drive, the risk can be multiplied. Chiu et al. (2015) also highlighted the unexpected challenges of responding to veldfires by public health. Everything and everyone is at risk during forest fires. You have to think of potential risks to hospitals, deploy veterinary emergency response to support the sick and wounded animals, plan for the disposal of animal carcasses and coordinate the disposal of debris from heavy or dangerous materials (Chiu et al. 2015).

Australia, following their wildfire had to deal with one of the most difficult issues in the psychological rehabilitation of the people. Loss of farms, assets and pets affected people. Long working hours, stress from responding to a major disaster, and personal loss had an impact on emergency responders. A huge number of the government employees were all impacted by the veldfire in that they had to be e vacuated or lost their homes (United Nations Environmental Programme[UNEP], 2020a).

2.7 Victoria veldfires scenario and coping capacities

During January 1939, bushfires spread through Australia’s eastern states (Stretton, 1939). Significant fires burnt through the other states, but the biggest area was burnt in Victoria, and most casualties were reported there. In his seminal study of the causes of Victorian fires, and specifically its impact on small forest towns and mills, Stretton (1939) concluded that ‘the whole tale of this small community’s killing is one of unpreparedness, due to apathy and indifference and maybe something worse’. In some situations, people did not seem to realize the full extent of the danger or know how to protect themselves. Stretton also argued that in many cases the prevention and preparedness strategies were well known, they were not implemented, either through apathy or conflict of competing interests. Griffiths and Brook

(2009) argue argue that the 'much worse' than Stretton was attempting to portray 'was an aggressive, half-conscious ignorance of the fire danger and some form of collective involvement in transferring blame'. It is not enough to know how to avoid fires, how to fight fires, how to plan for fires, and how to stay healthy during fires without the effort to enforce them and act on knowledge.

Krusel and Petris (1992), argued in their study that though our understanding of fire and fire safety continues to improve, loss of life and property can no longer be blamed on the lack of veldfire knowledge. The problem of why assets and people remain at excessive fire risk today is about a lack of adoption and implementation, not a lack of available information. Despite the unprecedented scale of the casualties and damages in the February 2009 Victorian fires, Black Saturday shared several parallels with previous fire deaths. Without proper planning, too many people were exposed to fires. Too many people thought they did not find themselves at risk. Too many people did not understand the alerts as a threat until it was too late to properly respond. While the fire's ferocity in some locations exceeded expectations of even the experienced people, unpreparedness undoubtedly contributed to too many tragic casualties.

Wahlquist (2019) in his article reported that in 2019 residents of East Gippsland threatened by out-of-control bushfires were advised to evacuate their homes, with temperatures forecast to hit as high as 43ºC in parts of Victoria. Melbourne was expected to reach 38ºC around 4 p.m. on the Monday before a sudden drop to around 8 p.m. at 22ºC. Mildura, in the northwest of the state, was expected to hit 43ºC before its cool transition. Swan Hill was forecast to hit 42ºC, 200 km south-east of Mildura. In the early afternoon, three out-of-control bushfires were burning at East Gippsland. The affected areas included Murrindal, Bruthen, Settlement Timbarra, and Sunny Point. In NSW firefighters in the meantime, were already struggling to suppress 48 uncontained fires. While cooler Sunday temperatures helped their efforts, by Tuesday they were bracing for temperatures above 40ºC in parts of the state.

Victoria State Government (VSG 2020) in their research papers found that the fires of 2019-20 happened on an extensive national scale. Hence, the impacts Victoria has experienced, in relation to the national emergency, are considered here. The overall veldfire death toll was a total of 33. This number includes five citizens of Victoria between the ages of 28 and 78, three South Australians, and 25 citizens from NSW. Five firefighters were among the victims, including three from the United States who died after losing contact with control crews when their water bomber plane exploded in North NSW. While damaging more property than the past big fires, the fires took fewer lives in 2019-20 than Victoria's Black Saturday in 2009 (173 fatalities) and Ash Wednesday in 1983 (75 fatalities). More than 300 homes were ultimately destroyed in Victoria. In Victoria more than 1.2 million acres were burnt, making it the largest veldfire since 1939, when 1.5–2 million hectares were burnt. The Black Thursday fires that occurred in 1851, which burnt about five million hectares. According to an analysis of the new Department of Environment, Soil, Water, and Planning (DELWP) veldfire survey, about 60% of Victoria's parks, more than 50 national parks and nature reserves, have been threatened by fires as of 11 January 2020. Victoria's worst air pollution exposure occurred on 13–14 January 2020, according to AirVisual, a Swedish air quality monitoring company that measures air quality in compliance with the United States Environmental Protection Agency National Ambient Air Quality Standard (VSG, 2020)

2.7.1 Coping capacity

Psychological preparedness underpins and precedes physical preparedness, ensuring healthy decision-making before and during the intense stress of bushfires, facilitating not just survival but also recovery (Clode, 2010).

The human capacity to react, cope, recover, and adapt is a crucial feature of susceptibility (Timmerman, 1981). Vulnerability is described in the early formulation of Timmerman in terms of a system's propensity to react adversely to the occurrence of a dangerous event. The type and length of the adverse reaction are said to be determined by the resilience of the system, and its ability to resist and recover from the impact of a dangerous event. More recent concepts of vulnerability underline the active capacities of individuals, rather than systems. Here, the principle of Wisner and Forham (2014) is important: 'with vulnerability we mean the characteristics and circumstances of a person or group that affect their ability to cope with, resist, and recover from the natural hazard effect'. Similarly, Hewitt (2013) believes that vulnerability exists when the powers of social institutions impair people's capacity to avoid, resist or recover from damage.

Definitions of coping or adaptive potential are nestled within capability-focused risk concepts. In climate change science, 'adaptive ability' is commonly used to refer to 'the ability of a system to modify or alter its characteristics or behaviours to better cope with current or expected external stresses' (Adger, Arnell and Tompkins, 2005). Since this section focuses specifically on communities, adaptive capacity is used to describe the capacity of communities to respond to new circumstances created by their knowledge of hazards or disasters.

2.7.1.1 Mental preparation and recovery

In the study of the Australian Psychological Society (2020) it is suggested that if you have already planned mentally for a bushfire, you are more likely to adhere to a household strategy. Being able to control feelings in an emergency (that is, being prepared psychologically), will save others' lives and possibly their own. Hot days and the possible risk of further bushfires will cause higher anxiety in people. Children are also vulnerable, and increased media attention and conversation about fires will lift their alarm level in the community, schools, and at home. Parents and caregivers should help children understand the risks, but they can also reassure them that they are safe and protected. Following a traumatic experience, one of the best things we can do for ourselves is to spend time with people who care about us and feel the social support of friends, family, and community.

UNEP (2020b) reported that, following bushfires, people will struggle with a range of issues, from cleaning up their houses to worrying about their partner's arguments or struggling to properly supervise children in a new or altered environment. Doing enjoyable things is an important method to achieve a sense of control and intent in life.

2.7.1.2 Victoria Personal Hardship Assistance Program

According to the Funding Centre (2020), if a community or single household has been harmed by fire and they are experiencing financial distress, they may be entitled to emergency assistance and/or emergency re-establishment compensation. Support for emergency relief may be available for a period of up to seven days after the disaster. To help meet immediate needs, it makes a one-off donation, including food parcels, temporary shelter, clothing, medication, and hospitality. There were grants of up to $2 000 available to assist Monash students if students have been impacted by the veldfires in 2019/2020. The grant money could be used for living expenses, computers (to comply with BYOD requirements), course materials, or other unexpected expenses.

Maillard (2020) reported that for the Victoria 2020 land tax assessment, businesses, families, and individuals whose properties have been destroyed or seriously affected by bushfires may receive an ex gratia relief payment. Property tax was also waived on eligible properties that were used to provide free housing for those who needed it. For people who chose not to restore property their own communities and chose to buy a home elsewhere, the state gave up to $55 000 in stamp duty assistance. People who lost automobiles due to veldfires received up to

$2 100 in ex gratia exemption from the tax on up to two new cars. For principal producers affected by veldfires (including apiarists) across Victoria, the Victorian State announced relocation grants of up to $15 000. Primary producers may request subsidies for eligible transport costs that impacted the immediate needs of the animal welfare system directly (Maillard, 2020).

Collateral free interest rate loans were made available in the three local government areas of Baw Baw, Cardinia and Latrobe to eligible primary farmers, small businesses and non-profit entities whose properties have suffered substantial harm as a result of what was known as the 2019 South East Victorian veldfires (started on 28 February 2019). To create the Victorian Bushfire Appeal, the Victorian State partnered with Bendigo Bank and the Salvation Army, and 100% of the funds raised went straight to families that needed it the most. The National Parks & Wildlife Foundation established the Victoria Wildlife Heroes Emergency Fund to provide support for Victorian licensed wildlife shelters and incorporated wildlife rescue and rehabilitation organisations working in Victoria. Initially, this initiative would help support emergency response for bushfires and excessive heat events (Funding Centre, 2020).

For those affected by the veldfires in 2019/20, the Victorian State provided several tax relief measures. Tax-relief initiatives included: (i) Exemption from land tax until 2020 if the property has been lost or heavily burned. (ii) Grants of up to $55 000 in duty on property transfer (stamp) to replace a home damaged by veldfires. (iii) Elimination of up to $2 100 in motor vehicle customs duty for vehicles damaged by veldfire when buying a new vehicle (iv) Other forms of fiscal relief were available and were handled on merit (Funding Centre, 2020).

2.8 Prediction of veldfire intensity using the Keetch-Byram Drought Index

Rahman et al. (2018) in their study found that fire is an increasing feature of the Australian countryside and predicting forest fire danger accurately within short range is critical not only for effective fire fighting, but also for the permitted burning opportunities to reduce the amount of fuel. In Australia, the McArthur Forest Fire Danger Index is used to estimate the likelihood of veldfires. This is an Australian-developed empirical model for dry sclerophyll forests. The inputs to this model are the present drought factor (as a fuel moisture measure) and the relative humidity, temperature, and wind speed. In reality, the fire hazard is calculated from observation and manual data input at point locations.

The National Drought Mitigation Centre (NDMC 2020) states that the drought factor is an analytical calculation of the moisture content of the fuel that depends on recent substantial rainfall by direct rain wetting and soil moisture wetting from below. Therefore, for predicting the current moisture status of the fuel, accurate prediction of current soil moisture is an important consideration. The Bureau of Meteorology uses two models of soil moisture balance to determine the danger of forest fires. The KBDI is Australia's most widely used soil moisture deficiency indicator. The Soil Dryness Index, established in Tasmania, is the second model for soil moisture. To forecast soil humidity, both the grid daily rainfall analysis and the grid daily maximum temperature are used. The rainfall analysis is valid for all of Australia at a resolution of 25 km and over the south-east at a resolution of 10 km where the observation network is denser to enable the higher resolution. In both versions, the average soil moisture deficit is 200 mm and the zero soil moisture deficit reflects the field potential (NDMC, 2020).

In the De Groot et al. (2006) report, it was found that warning system integration is a vital aspect of a fire safety programme to ensure that the organisation in charge is prepared for possible future fire catastrophes. Many other nations have developed highly advanced Forest Fire Danger Rating Systems, such as Canada, Australia, and the United States. Such systems are still very difficult to introduce in developing countries, as they are dependent on many meteorological data and require complicated calculations. East Kalimantan's example shows that weather stations and equipment like the one standing in the above-mentioned countries simply do not exist and will not be operationally in use for the near future. This study aims to illustrate methods that are very affordable and easy to classify fire hazards and provide assistance in setting up such a program. The KBDI offers a more practical analysis of the fire threat situation when the rain is less, while the Nesterov Index shows the increased fire hazard in periods of severe drought more dramatically. This approach is ideally suited to particular forest protection situations in developing countries, provided that the cost of a simple weather station, which is reasonably observable in the case of the Nesterov Index, is very small for humidity, rain and temperature and a weather station capable of measuring rainfall and maximum temperature for the KBDI. In the analysis by Cawson et al. (2018) they observed that there are contradictory hypotheses about how after disturbances such as logging or wildfire the flammability of wet eucalypt forests shifts in the period. Others conclude that forests are most inflammable in the subsequent decades of disturbance, while others conclude that disturbance has no flammable impact. It is not clear how *Eucalyptus nitens* plantations are comparatively flammable in the same climate as wet eucalyptus forests. Cawson further calculated the fire frequency and extent of fire in wet eucalyptus forest, re-growth, new, and old growth, and *E. Nitens* plantation in the Huon Valley, Tasmania following wildfires in January–February 2019. He randomly selected sites within the footprint of the fire to monitor topographic variability and fire conditions, and then randomly located a paired site within 3 km for each in different types of forest in the same topographic region. On the same day, every pair of sites were burnt. The least likely to burn were old-growth forests and plantations. Old-growth and mature forest showed scorched crowns of eucalyptus to a much smaller degree than forests of regrowth. In a comparison of paired locations, plantation forests were less likely to burn than mature and old-growth forests combined, but the plantation canopy was scorched in all cases of observed ignition. The lower flammability of older trees, and their value as an increasing carbon reserve, suggests that a cessation of logging outside plantations may have significant advantages (Cawson et al, 2018)

Kumar and Dharssi (2015) in their study explained the KBDI programme is used to measure seasonal dryness and employs a bookkeeping approach to monitor the loss of soil moisture, and uses a simplified evapotranspiration relationship based on daily maximum temperature to estimate the loss of moisture and daily rainfall adjusted for forest interception for a refill. The KBDI has a scale of 0–200 mm (0 = field capacity of the soil, 200 = moisture of writing point). In 1965 McArthur, in southeastern NSW, made a correlation of the index with forest fire behaviour. He found that extreme fuel forest fires occurred in the mountain country when the drought index reached 100 mm as all the fine fuel and most of the course fuel on the forest floor dried out enough to burn regardless of its position on the ground. McArthur also noticed that significant forest fires could be predicted at an index value of less than a 100 the following spring and summer when the KBDI did not reduce to zero for two or three months over the timespan. In 1966, the KBDI was brought into practical use in Australia (Kumar, 2015).

Jin et al. (2015) found that the severity of the fire varies across the perimeter because the rate of spread of each part of the fire perimeter varies with respect to the prevailing wind according to its location. At the head of the fire where the spread rate is the highest, fire intensity is the highest, and the lowest intensity is in the back of the fire where the spread rate is the lowest. The fire rate for head fire is usually quoted unless otherwise specified and is optimum for the entire perimeter. The measured fire intensity statistic is useful when comparing fires of the same fuel type. However, since the fire behaviour and the spread rate depend on the fuel structure and the available fuel load, fuels in fires that are structurally different in their intensity is measured the same. Nevertheless, fire intensity is useful to demonstrate changes in fire activity such as flame height and duration and to provide estimates of suppression ability in the same forest type by different techniques (Cawson et al, 2018)

2.9 Veldfire management policies and regulations

The Voluntary Guidance on Fire Management states that 'any fire prevention practices should be based on a legal basis and underpinned by specific processes and regulations'. Therefore it is clearly understood that forest fire control is institutionalised and several strategies can be envisaged. The law generally encourages the administration of powers, rights and responsibilities, the recognition of relationships between different individuals and entities in a field, and the establishment of dispute resolution mechanisms and the enforcement of rights and responsibilities (FAO, 2006).

In the specific field of forest fires, legal policies can use a preventive and punitive approach to regulate human activities in or around woodland (farming, harvesting, and forest management) aimed at reducing forest fire hazards. Bans may be necessary if the threat is high and those responsible for forest fires need to be reported and punished in accordance with the extent of their responsibility and the harm caused (FAO, 2001). The law would also justify the continued use of fire, ensure accountability in the regulation of fire and ensure that operators use it safely, as well as provide a mechanism for cooperation between land managers, landowners and fire fighters. From a management planning perspective, regulations should identify planning functions, develop basic guidelines for inter-institutional collaboration and public participation, and ensure that plans are implemented in multiple fields, are regularly updated, and have some legal consequences. Legislation can also provide incentives for the safe use of fires and the prevention, detection, and suppression of forest fires. It can also provide a framework for the allocation of public funds to other fire-related activities (FAO, 2006).

Thanks to knowledge and viewpoints obtained through public consultations, the FAO has gained more knowledge and recommendations in many countries' participatory statutory drafting of legislation, and it contributes significantly to the performance and clarification of the law. Moreover, there is usually an increase in public acceptance and conformity with the legislation were sense of possession and credibility are nurtured (FAO, 2001)

2.9.1 International veldfire policies and regulations

Based on regional representation, a few countries were selected to illustrate the various types and structures of national veldfire legislation and how the regulations on veldfires apply to the other aspects of law in a particular region. All of the following sub-sections are purposely structured in a different way to underline the variety of possible solutions. Significant examples of decentralized alternatives to veldfire regulations are Argentina and Senegal. Indonesia, on the other hand, provides a useful example of community-based approaches to fire safety, whereas the Russian Federation mainly comprises leased forest fire control holders. The combination of policy and legal resources to combat veldfires was selected by both Europe and the US. Finally, the two legislative frameworks apply to the main theoretical aspects of national forest fire legislation that will be formulated and discussed based on more examples of national legislation (FAO, 2006)

- **European Union**

  Christy et al. (2006) found that it is the primary duty of the member states of the European Union (EU) to prevent and control veldfires and to enact and develop their national legislation in this regard. Nevertheless, the EU supports the efforts of its member states by setting veldfire policy priorities for agroforestry, providing financial support for programmes related to veldfire, and establishing a common information system for forest fires. The instruments adopted for these effects by the EU may apply not only to EU member states, but also to other applicant countries, or otherwise to EU countries, and may gain from such EU help.

  Based on the EU Forestry Policy, the 2006 Council of Europe adopted a Five-Year Forest Action Plan (2007–2011) (Communication from the Commission to the Council and the European Parliament on the 15 June 2006 EU Forestry Action Plan). The Action Plan aims at improving competitiveness in the long term, enhancing and protecting the environment, adding value to the standard of living and facilitating teamwork and engagement. To this end, it proposes several veldfire-related steps to be taken either collectively by the EU and the member states, or by the member states, with the assistance of existing community instruments (FAO, 2006).

- **Argentina**

Gutman (2018) in his report explains that legislation on veldfires in Argentina is enforced at three spheres of government – central, regional and local, in compliance with the National Constitution (Articles 75 and 121) and each province's constitutions. National forest legislation offers a comprehensive framework for the protection of woodlands from combustion, while provincial governments may pass laws implementing national standards at the regional level, as well as establish more stringent policies than national ones. Regions may also allow municipalities to take more legislative action on a given issue through their legislation. The National Fire Management Plan was established by the Department of Environmental and Sustainable Development within the Ministry of Social Development and Environment, to define the functions and obligations associated with veldfire management at the provincial and national spheres (Resolution no. 465/9611) (Gutman, 2018).

Environmental Protection of Native Forests Argentina 2007, contains the core rules for the protection of forests. It is devoted solely to veldfires and accounts for general duties. The Act regulates the burning of woodlands, specifying that fire can be used only under the conditions laid down in the veldfire protection laws. The National Forest Authority may decide appropriate fire uses and take the required measures to avoid, fight, and circumscribe forest fires (EPNFA, 2007).

- **Indonesia**

The Forest Legality Initiative (2016) in their report explained that the Republic of Indonesia's Constitution of 1945 assumes the sole responsibility for government woodland management by declaring that land and natural resources should be managed by the state and used for veldfires and the greatest welfare law of the nation. More and more competencies, including those related to veldfires, have been moved from the national government to provincial governments as part of the development planning that followed the 1998 reformation. The judicial system is undermined by the fact that other pre-1998 statutory instruments have not been specifically abolished but remains in force as long as they do not interfere with more recent measures. Furthermore, as most enforcement of the post-1998 instrument depends on the passage of subordinate policies, this often takes longer (FLI, 2016).

The primary statutory instrument in the field of veldfires is the Forest Law (Law No. 41/1999, as amended by Law No. 19 of 2004), which sets out the supporting standards for woodland management. It states that, for the betterment of the public, all woodlands are under the authority of the state, allowing the government to control and coordinate all aspects of woodlands, protected areas and woodlands products (Article 4). As far as veldfires are concerned, the Forest Law remains somewhat wide and unclear, containing only a few rules on the subject and excluding the most detail on compliance with central and regional regulations, decrees and other steps. The administrative framework relating to veldfires is mainly governed by the Law on Decentralization (Regional Administration Law No. 32/2004) and by the Government on Local Governance Act No. 38 of 2007. Also, some unique legislative decisions have established mechanisms explicitly or implicitly linked to veldfires. A Central Integrated Forest Safeguarding Team was created by Presidential Decree No. 22/1995, which is responsible for formulating coordinated forest protection policies and is responsible for monitoring, supervising and coordinating the implementation of such policies (FAO, 2001)

2.9.2 Australian veldfire policies and legislation

The international community for the management of veldfires is expanding in depth and complexity. The growth of cooperation arrangements used by lawmakers during difficult fire seasons to share resources is one important development. Australia enjoys beneficial partnerships with overseas property, fire and emergency response agencies, especially in New Zealand, the United States and Canada. In addition to the sharing of information and emergency assistance, important opportunities to strengthen these relationships exist (ACT Government, 2019) .

The report by the Australian Capital Territory [ACT] Government (2019) stated that after the devastating January 2003 veldfires, the ACT government and community have been vigilant in introducing measures to provide the residents, properties, and the environment with greater protection against veldfires. The ACT Emergency Services Agencyhas successfully implemented three Comprehensive Bushfire Management Plans over the past 15 years under the 2004 Emergencies Act.

The National Declaration of Bushfire Management Policy for Forests and Rangelands was created, and in 2011-2012, all members of the Council of Australian Governments, including the Australian Local Governance Association, backed the declaration. The statement is consistent with the Voluntary Fire Management Guidelines of the, which were developed at the third International Wildland Fire Summit in Sydney in 2003. The voluntary recommendations was subsequently endorsed by the eighth session of the FAO Committee on Forestry in March 2007 and the fourth International Wildland Fire Summit in May 2007 (FAO, 2016).

The statement outlines accepted priorities and plans for the future development of large areas or landscape fires in Australia's forests and rangelands. This is partly a backup response to the veldfire Prevention and Management National Inquiry's 2004 Council of Australian Governments report. This declaration also contains relevant parts of the National Forest Policy Statement (released by the Council of Australian Governments in December 1992), the 2010-2030 Australian Biodiversity Conservation Plan (released in October 2010), which aims to ensure that our ecosystem is 'safe and adaptive to changing environment, and valued both in its own right and for its significant contribution to our lives', and the Native Australian Vegetation Framework (released in December 2012) which aims to manage native vegetation in 'an environmentally sustainable way that promotes its enduring environmental, economic, social, cultural and spiritual values'. The declaration also complements the Sustainable Resource Management Rangelands Principles (National Wildfire Coordinating Group, 2016).

A diverse range of biodiversity and agricultural lands are found in Australia and it is characterised by pronounced regional differences and different population values. In Australia, fire protection requires rules and policies consistent with people's needs. To be able to effectively anticipate and respond to drivers such as climate change, a deeper understanding of veldfire hazards and biodiversity shifts in community behaviour, and trends of land use and growth, veldfire policy frameworks must also be adequately adaptive. This declaration provides a sense of direction, principles, policy goals, and strategies to handle landscape burning for Australia's land and fire managers. These guidelines will direct land and veldfire management instruments and procedures (e.g. codes of practice) to ensure that they are implemented at operational level. Land and fire administrators have important tasks and duties to achieve the specified objectives. These are: (i) Use of planned fire to minimize fuel and preserve safe, efficient ecosystems; (ii) reducing unforeseen and unplanned incidences of unfortunate fires; (iii) prepare for unexpected fires close to its ground, and respond quickly; (iv) managing veldfires, to lead to positive results where possible; (v) leading and supporting emergency operations where necessary; (vi) closely working with the communities and stakeholders and associates; (vii) training through research, surveillance and adaptive steering; and (viii) the application of best practices by establishing and modifying the codes of practice of their agencies to conform to the values and policies found in the National Bushfire Forest and Rangeland Policy Statement (FAO, 2016)

2.10 Commonly used conceptual frameworks in disaster management studies

The ability to measure vulnerability is continually used as a critical move towards the effective management of risk and the promotion of a culture of disaster resilience. If science is intended to help facilities the transition to a more sustainable environment, measuring vulnerability is a critical challenge considering the frequency of disasters and the continuing deterioration of the environment (Kasperson and Pijawka, 2012). Kofi Annan emphasized that threats only become disasters when the people’s livelihoods are removed from them. His perspective conflicts with previous research and procedures, most of which were purely risk-oriented (Lewis, 1999).

Rather than just defining disasters only as physical events needing largely technological responses, catastrophes are better described as a product of the complex relationship between a physical occurrence that is potentially harmful (for example storms, veldfires, hurricanes, and tornadoes) and the vulnerability of a society, its facilities, economy, and climate determined by human actions. Perhaps it should be understood in this sense that natural disasters are ‘unnatural disasters’ (Birkmann, 2006). Therefore, the creation of disaster-resilient societies requires a paradigm change away from the primary focus on natural disasters and their quantification to the detection, evaluation, and rating of different vulnerabilities. It is one of the United Nations Institute for Environment and Human Security projects to contribute to the identification of different vulnerabilities and to the production and testing of relevant indicators and assessment methods to further extend the environmental component of human safety (Brauch, 2005).

The Hyogo Framework stresses the need to define vulnerability markers as ‘primary activities’; the development of national-level disaster risk analysis and vulnerability indicator systems and provincial scales allow decision-makers to determine the impact of disasters in social, economic and environmental environments and to disseminate information to accounting officers, and communities at risk. The action may be interpreted as involving a correlation between vulnerability assessment and environmental sustainability. Furthermore, the resolution illustrates the need to develop methods and indicators which, based on those recommendations, can be used in strategy and decision-making processes. Also, it is obvious that calculating vulnerability needs a strong understanding and description of the concept of vulnerability in the first place (United Nations [UN], 2019).

Vulnerability is concept that developed from sociolog in the 1970s and is known as a rection on the peril during disaster risk. Since the 1980s, the strength of peril forecast methodologies is dependent on specialized mediations that have been progressively tested by the international view of utilizing vulnerability as the beginning stage for the chance to decrease. This methodology consolidates the vulnerability of individuals and networks uncovered with their social, financial, and social capacities to adapt to the harm that could happen (Gough, 2010).

Also, a few scholars consider social vulnerability as something that manages the defencelessness of individuals and physical vulnerability as the conditions essential for human resilience and adaptation. In this setting, biophysical vulnerability is an idea developed from the worldwide study of natural change, where it is generally used to depict the degree to which a framework is powerless against unfavourable impacts of environmental change and to what degree it is (un-)ready to adjust to such effects Despite the fact that what the word weakness encompasses is still a lot of vulnerability, Cardona (2004) stresses the way that the definition of vulnerability helped to clarify the concepts of hazard and catastrophe. He sees vulnerability as a characteristic propensity to be affected by or to be defenselessly vulnerable to harm.

The United Nations International Strategy for Disaster Reduction (UNISDR) formulated one of the best-known definitions, which define vulnerability as the circumstances determined by or processes of physical, environmental, cultural, and social factors that increase a community's vulnerability to the effect of hazards (UNISDR, 2004). The United Nations Development Programme (UNDP) describes insecurity, by comparison, as an individual state or mechanism arising from physical, socio-economic, and environmental factors affecting the probability and extent of harm resulting from the effects of the hazard in question. (UNDP, 2019).

For the interpretation of vulnerability, the Bogardi-Birkmann-Gardona (BBC) conceptual framework was suggested. This conceptual model sketched a firm theoretical framework in vulnerability literature for the study and assessment of exposure and vulnerability. The BBC model is presented in this paper as shown in Figure 2.7, as it helps us to examine the three elements of vulnerability. These are exposure, vulnerability, and veldfire adaptability in the region of analysis. The system also blends threat and vulnerability with an intent to reduce risk. The method was used for evaluating variables and interpreting tests (Birkmann, 2006).

The BBC model stresses the point that vulnerability analysis stretches beyond estimating weaknesses and analysing the impacts of disasters in the past. This emphasises the need to view vulnerability within a process, which ensures that vulnerabilities, coping mechanisms, and potential vulnerability management mitigation techniques are centralised at the same time. Moreover, insecurity should not be seen as an isolated function, as seen in the theoretical framework for the BBC. Instead, the assessment of vulnerability also needs to consider the unique form(s) of threat and future event(s) to which the vulnerable population, financial systems and climate are susceptible, as well as the risk-causing interactions between the two. The BBC model stresses the need to reflect on the socio-economic and environmental and dimensions of vulnerability, specifically linking and integrating the concept of sustainable development into the sense of vulnerability. Additional structures can be incorporated into the three sustainability dimensions (private, economic, and environmental) (De Almeida, 2014).

The BBC conceptual model opposed to risk analysis, focuses primarily on various vulnerable or susceptible elements, coping capacity, and possible preventative strategies to mitigate the vulnerability.

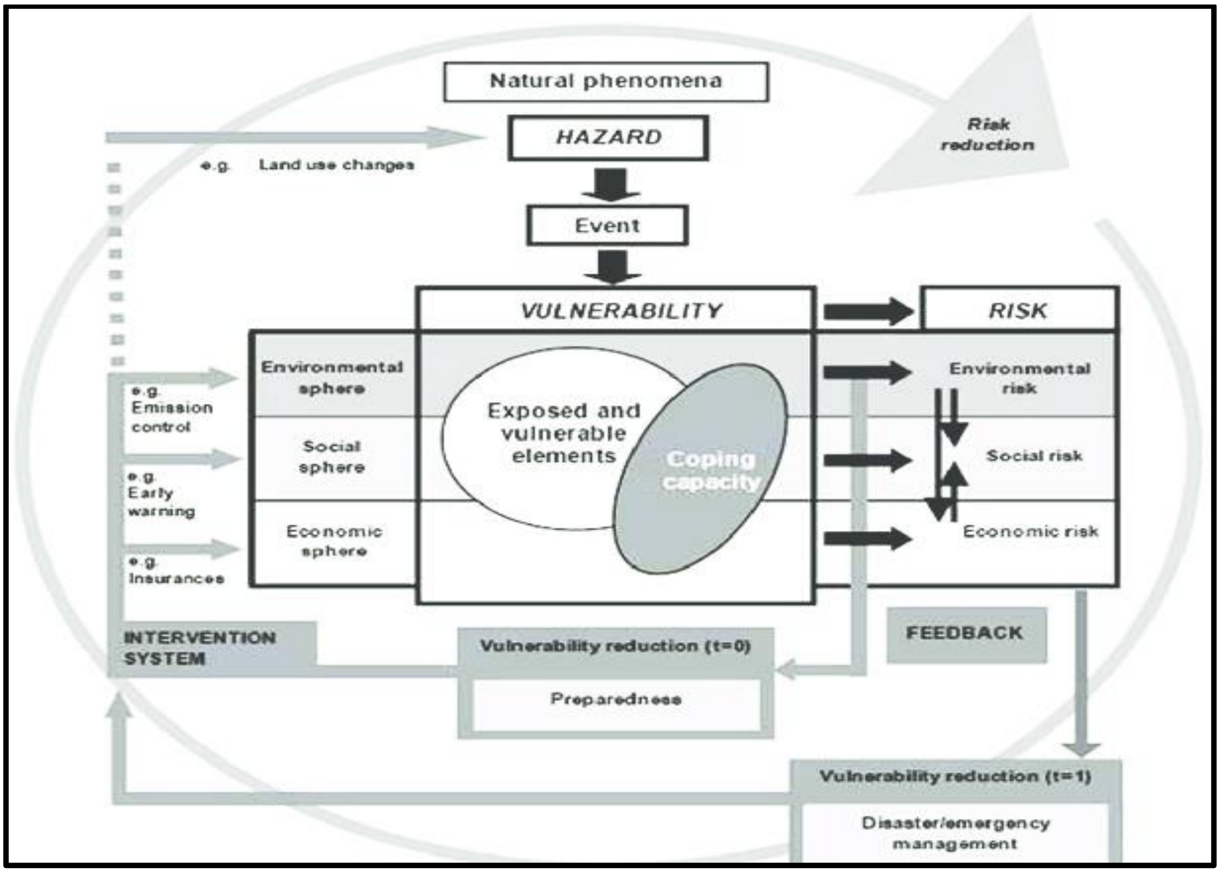


Figure 2.7 Conceptual model of vulnerability (Bogardi-Birkmann-Cardona model) (Source: Birkmann, 2006)

The conceptual structure of the BBC model stresses the need to give due consideration to environmental factors, on which human circumstances rely, through the connections between environmental sustainability and the elimination of vulnerability. Organisational and systemic aspects, as well as physical vulnerabilities, are significant, but the three interrelated areas (economic, social and environmental) should be studied. Furthermore, by analysing the possible vulnerabilities and limitations of the various at-risk elements (e.g. social groups) and their coping skills, as well as potential prevention strategies, both within the three major thematic areas, the BBC model encourages finding solutions to the problems. This shows how critical it is to be proactive in raising vulnerability before an incident hits society, economy, or climate (Turner et al. 2003).

The BBC model's conceptual structure acknowledges the phenomenon of exposure, partially because it recognises that the location of human settlements and facilities plays a significant role in assessing the vulnerability of a group (Field et al. 2012). It acknowledges, however, that within the specified high-risk zone, other features can have a significant impact on whether or not residents and facilities are prone to suffer damage. In addition to exploring the vulnerable elements of culture, the economy, and the environment, the conceptual structure of BBC model demonstrates the importance of minimising danger by eliminating vulnerability and lessening hazards even before danger can occur. Vulnerability assessment should also include the identification and evaluation of potential mitigation strategies for the different vulnerabilities and the development of a population or system at risk's coping capabilities (Jamshed et al. 2020).

Ultimately, the model emphasises that shifts in vulnerability must be considered and viewed as a problem from one thematic element to another, as these changes do not imply actual vulnerability reduction. When an organisation covers its financial vulnerability by cutting loans to its employees in a crisis scenario, then it is the employees who will have to cope with the negative financial consequences of the incident. The company shifts its risk (economic risk) to the workers (social sphere) because of the lack of adequate disaster insurance, but without any specific reduction in overall vulnerability (Turner et al. 2003).

2.11 Pressure and Release Model

Blaikie et al. (1994) proposed the Pressure and Release (PAR) system in an attempt to explain the relations between growth and vulnerability formation. In reaction to criticism of the risk-hazard strategy, the PAR system emerged. Hazard is characterised as a feature of a natural hazard and social vulnerability in the PAR system. The natural disaster that affects a vulnerable population is just the catalyst that triggers a catastrophe. The PAR model therefore does not emphasise the risk itself, but the social, political, historical and cultural structures that establish dangerous conditions for individuals. While the risk-hazard approach sees vulnerability as a result, vulnerability is seen as a complex mechanism governed by socio-economic forces in the PAR system (Wisner et al. 2003).

2.11.1 Hazards

The BBC Vulnerability Model starts in this analysis with veldfire and smoke as the chosen hazards from which vulnerability is assessed.

- **Veldfires**

  Veldfires are a common part of the Australian climate and can come about as a result of natural phenomena like lightning (Nolan and Thornton, 2016). The existence of human populations can also increase the risk of fires by accidental or deliberate ignition. Australia's natural vegetation is well suited to fire, but vegetation can also be a source of specific hazards. Oils found in eucalyptus can be extremely volatile, and certain species' barks can produce embers that disperse the fire over long distances (Lallanilla, 2013).

  A variety of natural conditions such as temperature, humidity, and wind speed influence the veldfire threat. The pattern of southerly wind changes makes Victorian bushfires particularly hazardous (Price, Marz and Grant 2012). A fire pushed by winds from the north to the west can turn into a big and unpredictable firestorm when a sudden shift to southwestern winds hits. This rapid change in wind conditions has affected the most deadly fires in Victoria's recorded history, for example, Black Friday (1939), Ash Wednesday (1983), and Black Saturday (2009). These three fires alone have accounted for 62% of all Victoria bushfire deaths since 1900 (Sturzenegger and Hayes, 2010).

  Inquiries and royal commissions undertaken following major fires have led to a phase of recognising bushfires and to develop them further. There have been policy initiatives and improvements in urgent management and land use planning. Where a veldfire management overlay applies, a veldfire hazard assessment is needed on and around the land in question. After this, the development of measures to protect against veldfire is required. In addition to these planning criteria, building standards in designated veldfire prone areas are required. The identification of these areas is now required in land transaction documents (Oackly, 2020).

- **The impacts of veldfire smoke**

Fire is the normal emphasis in terms of real flames, as people talk of fire danger. Smoke, however, can also pose a significant threat. For those with underlying conditions such as asthma, the fine particulate matter created by bushfires may pose a particular danger (United States Environmental Protection Agency [EPA] 2019. These breathing difficulties may put the older people and children at particular risk. The risks posed by smoke vary according to the form of fire. Using case studies, Whittaker (2019) found that large extreme short-lived fires (such as those during Black Saturday 2009) had high columns of convection that carried smoke into the upper atmosphere where it could spread away from communities. In contrast, the bushfires created a much greater risk of smoke over a much wider area during 2006–2007 (EPA, 2019)

The 2006–2007 fire seasons in the Alpine region was noteworthy for the very long period during which major fires were burning. Between December 2006 and February 2007 some 1.2 million hectares of Victorian bushland were devastated by fire. The duration of the bushfire outbreak and the intensity of the prevailing winds meant that not only were the affected communities in close proximity to the fires but also was over larger areas of the state (BBC News, 2019). The fire burned mostly in the Alpine regions, which meant property damage and life loss were lower than anticipated for such a big fire. However, when major cities such as Melbourne and Geelong were affected, the number of people exposed to smoke during the three-month period, was very high. Coal and peat fires can also pose increased risks from the smoke. Partly because both are exceedingly difficult to extinguish, they continue to burn for long periods, exposing populations to smoke threat longer than other veldfires. These fires can also produce localized problems from particular gas emissions such as carbon monoxide (Whittaker, 2019).

In 2014, a veldfire entered the wide-open cut coal mine in the Morwell area. While not the first time a fire had burned in the Gippsland coal fields, the proximity to residential communities and the amount of smoke pollution faced by the community over the next six weeks, was noteworthy. The key elements of concern were combustion byproducts and, in the aftermath of this incident, a mine fire inquiry suggested changes in air monitoring speed in response to these emergencies (Australian State of the Environment, 2016).

A peat fire in Cobden in 2018 posed similar questions about possible smoke risks and quick deployment of surveillance systems, along with society and other at-risk advice such as disabled elderly people and safety. With an ageing population, the population at of veldfire smoke are expected to grow in the coming decades (Jones, 2005).

2.11.2 Factors which affect vulnerability and resilience

- **Environmental sphere**

Impacts on the environment in Victoria include immediate and short term reductions in air quality. Both potable and commercial water quality are often adversely affected. Soil erosion can result from landscape denuding, and while events of rainfall may be welcome, they will only exacerbate this problem by polluting drainage basins (WWF, 2020). Losses of biodiversity are clear and frequently reported. It has also been suggested that the loss of wildlife corridors may have an adverse impact on biodiversity, especially with vulnerable or endangered species (Butler, 2019). Veldfires are highly capable of destroying drinking water sources in Victoria. The adverse effects on sources of drinking water generally express itself in two ways. First, fire destroys treatment or distribution plants, threatens water companies ability to filter raw water to clean water level, and/or provides consumers with filtered drinkable water. Second, the fire adversely affects the drainage sites from which the wastewater is collected. Fires in drainage sites generally lead to deterioration of the quality of raw water, which can lead to difficulties in managing the level of water supply (Victoria State Government, 2019).

- **Social sphere**

Direct exposure to fire and smoke causes immediate health impacts and it also increases stress. Like many of the physical aspects of climate change disasters, mental health issues are considered a significant issue. Extreme events such as heavy rains have mental health consequences, as does the lengthy continuation of extended dry weather patterns such as famine (Finlay et al. 2012).

More than 3 000 homes were lost during Black Saturday with devastating consequences. In these situations, individuals were forced to look beyond their neighbourhoods for temporary accommodation (Whittaker, 2019). People had to deal with feelings of social alienation, suffering and sorrow. Family violence was reportedly on the rise following natural disasters, and investigations were done to establish the connection between fires and relationship violence (Victoria Bushfire Royal Commission [VBRC], 2019).

Beccari (2016) in his research identified the factors that can make individuals and populations more vulnerable. Such variables were created by the Geoscience Australia Risk Impact and Analysis Group for use and are based on analysis of the literature and input from stakeholders.

These metrics were used in a population survey carried out in February 2009 following the Black Saturday fires in Victoria for the Bushfire CRC. The indicators may be important in situations pre-disaster (e.g. preparedness) or post-disaster situations (e.g. recovery ability). Vulnerabilities of the populations have a regional range. Some groups may have a greater measure of vulnerability than others and some places can have several forms of vulnerabilities. The metrics that represent an individual measure, a household's degree of vulnerability is determined by its weakest member rather than its strongest person (Commissioner for Environmental Sustainability, 2012).

Zimmer-Gembeck and Skinner (2016) found that some threats, such as drought, are sluggish and protracted while others, such as veldfire or floods, are sudden and involve rapid reaction. The finding that the duration and severity of these events may cause different perceptions of suffering may be important to understand vulnerability to an emergency's immediate effect compared to vulnerability over the longer recovery period. Below is the indicator of vulnerability pertinent for veldfire analysis (Table 2.2).

Table 2.2 Indicators of vulnerability pertinent for veldfire analysis

Identifier	Remarks
Young people	The very young are at risk as they rely on others for care.
Older people	The elderly tend to be frailer, have more health problems, and may depend on others for care. Although individual older people may be healthy and active, aggregate data indicate that, with age, the number of people who need support increases.
Single parents	Single parents can cope with dependent children's demands but without any external assistance.
Volunteering	People who perform volunteer service within their community are more likely to have social networks that can provide information, support, and services in times of emergency.
Income	Low-income households can face greater difficulties in material recovery from a disaster. They might also be underinsured or without protection.
New to region	If in recent years a person has moved to an area, they may not be familiar with local environmental hazards and may not be aware of procedures to prepare for or respond to an emergency.
Public housing	Socio-economic poverty is a prerequisite for accessing public housing, and poor individuals are likely to have a range of social and economic issues which could need extra assistance in an emergency.
Education level	People with high educational are more likely to understand a variety of risk- and preparation-related information, as well as knowledge about alerts.
Need assistance	Those who report needing self-care support are likely to require help in an emergency, e.g. with evacuation.
Car ownership	People without access to a car won't be able to evacuate in an emergency.
Insufficient English	People with limited English can find it harder to access or understand various messages and information concerning emergencies.
Unoccupied dwellings	Absentee owners do not have high rates of involvement with the local community, nor do they have the time on their property to attend meetings or to conduct complete fire preparations.

- **Economic sphere**

The size of the Victoria workforce in 2016 was 2 929 591, of which 1 012 503 were casual employees and 1 670 556 were permanent employees. In Victoria 2016, the analysis of employment status (as a percentage of the workforce) compared to Greater Capital Cities indicates a similar proportion of unemployed people as well as a similar proportion. In total, 93.5% of the workforce was working (0.0% of the population aged 15+) and 6.7% were unemployed (0.0% of the population aged 15+), compared to 93.2% and 7.0% for Greater Capital Cities, respectively (Australian Bureau of Statistics, 2020).

In 1995 Australian Social Trends mentioned that the workforce participation rate refers to the percentage of the people aged 15 years and older that it is employed or seeking work. A key contribution to domestic development is labour. Its size and composition are, thus, the main factors in economic development. From a social development viewpoint, earnings from paying jobs have a huge effect on the degree of economic well-being. A study in 2016 of the participation rate of the workforce population in Victoria indicates a lower level of the workforce (60.5%) compared to Greater Capital Cities (62.1%) (Australian Bureau of Statistics, 2020).

2.11.3 Coping capacities against veldfires in Victoria

On 5 February 2020 the Parliament of Victoria reported that during the 2019 fire season Australia has endured extraordinary temperatures and months of severe drought in a couple of major veldfires. Victoria, where 1.2 million hectares of fires burnt, extended a 'state of emergency' from 2 to 11 January for the worst-hit regions. There were still some blazes raging in the state, and emergency warnings were in effect. The military sent soldiers, ships, and aircraft to the area to assist with evacuation efforts and fire fighting. Three people, including one firefighter, have died as a result of the fires. A squad of 39 firefighters and two United States liaison officers have arrived to help respond to the crisis in Victoria. About 71 firefighters, 61 from the United States and 10 from Canada also assisted (VSG, 2020).

2.11.4 Veldfires preparedness measures

After the catastrophe of Black Saturday, Victoria's Country Fire Authority has implemented a 'Bushfire Protection Framework' framework to tackle concerns in its neighbourhood readiness initiatives. The Bushfire Protection Program shows that there is no simple approach to developing healthy communities and there is a strong collaboration between the role of government, culture and citizens in creating a safer world. A collective preparedness strategy would improve the resilience of neighbourhoods and mitigate the likelihood of veldfires (Sturzenegger and Hayes, 2010). The first concern in developing the Bushfire Protection Program was to analyse the risk management techniques that were necessary to be applied before the upcoming fire season, discussing the issues resulting from the 2009 interim Victoria Bushfire Royal Commission. Report (VBRC, 2009).

It is not unusual in its implementation to use a system solution to 'false' issues A system is a clear acknowledgement of a set of interrelated and interdependent components. The interrelation of components within the system is the special characteristics of the perspectiveof systems. A system has different strengths of its own: separation and integration (Robbins, Millet and Waters-Marsh, 2005).

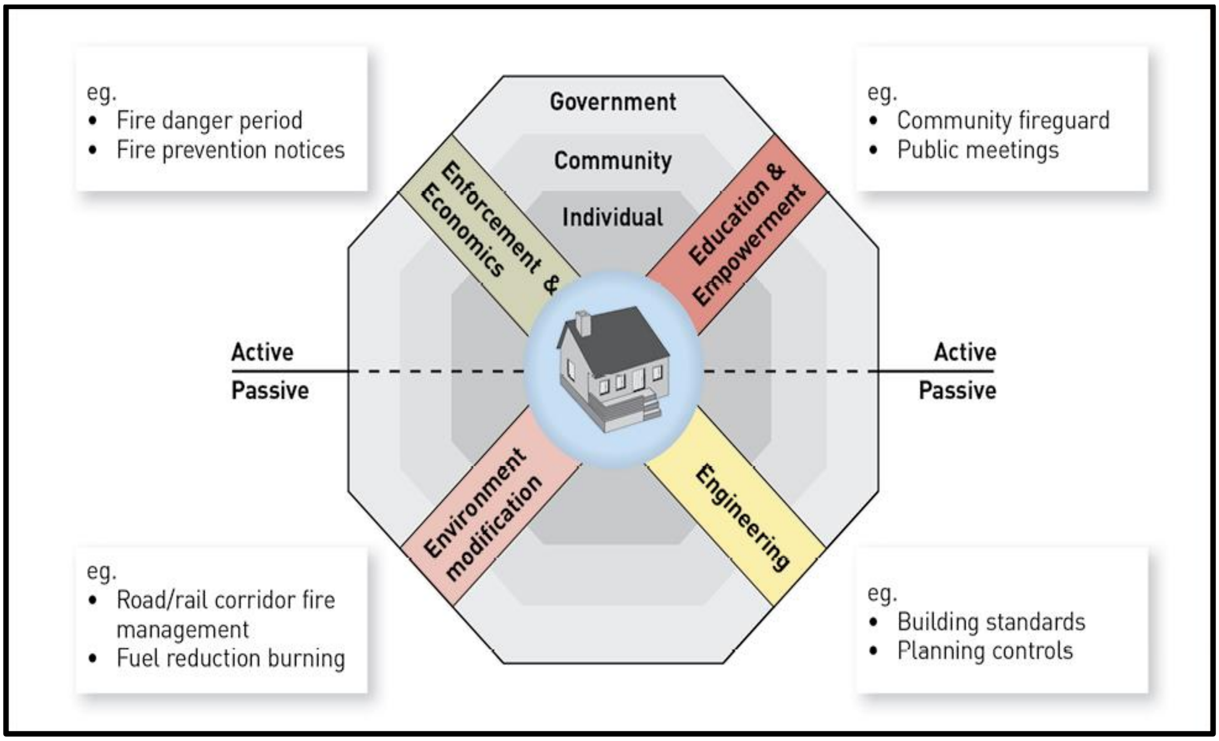


Figure 2.8 Bushfire Safety System (Source: Sturzenegger and Hayes, 2010)

Figure 2.8 describes a Bushfire Safety System. The model acts as a mix of interdependent and collaborative risk management initiatives that take into account government, community and individual roles, capacities and responsibilities. The weighting and size of the responsibility in the quadrant are not the same and relies greatly on the degree of commitment put into the risk management mechanism. The object of focus is often the individual household (Sturzenegger and Hayes, 2010).

The limitation of the Bushfire Safety System is that the optimal performance of elements of the Bushfire Safety Program can be influenced by several factors. No economic initiatives and restricted regulatory actions are currently in place. Tolerance and the political climate will affect the desire for incentives and disincentives for veldfire security outcomes and the Bushfire Preparedness Program sees substantial involvement in the Education and Empowerment Quadrant, which is often seen as the less successful hierarchy of ‘risk mitigation’ management, whereas considerable economic intervention in long-term infrastructure (Fairbrother et al. 2014).

- **Advantages of using the veldfire protection programme**

Using a systemic technique to the growth of Bushfire Preparedness Program, the opportunity was provided to participate in a strategic dialogue about the results that government agencies required to produce. This approach allowed for a needs assessment of the elements that had little to no involvement at the level of individual, community, to government expenditure to be carried out, allowing a more concentrated way to deliver the programme (Bushfire CRC, 2009).

Victoria's Country Fire Authority has integrated several data layers with the Department of Sustainability and Environment to help local decision-makers to identify 52 high-risk towns across the state. This project provided a critical focus on information regarding where and what measures should be taken to reduce the risk (McNamara, 2005). This galvanised the goal of targeting all 'most-risk' behaviours. It puts the strengths of several agencies into action by using a 'framework approach' and as a result, the partnerships across government departments have improved. The Victorian Fire Risk Register has now formalised the identification of communities at risk from bushfires (Gilbert, 2007).

2.11.5 Intervention system

The intervention system requires steps to minimise event frequency, severity, and vulnerabilities. The steps to minimise vulnerability to veldfires are those found in Victoria State. Under the Forests Act 1958 and in compliance with the Code of Practice for Veldfire Management on Public Land 2012, the Department of Environment, Land, Water, and Planning is responsible for managing bushfire threats on public land. To execute the goals of the two codes of practice, they control veldfire risk mainly through vegetation management. They should:

- Minimize the effect on human life, families, critical and national resources, manufacturing, the economy and the climate of major bushfires: attention should be granted to human life above all other interests.
- Preserve or improve the strength and the ability of ecological systems to provide resources such as habitats, soil, storage of carbon and woodland products (Birkmann, 2006).

The most effective way to control the possibility of veldfires in wide areas of public land is to monitor fuel management. Fuel control decreases the amount of fuel available to a veldfire, which can minimise its size and spread, and therefore improve firefighters' chances of suppressing it. Fuel are mainly handled through scheduled burning, and also through mechanical processing. For fuel management purposes, Victoria is divided into four fire protection areas:

(i) Asset Protection Zone: the land surrounding properties and facilities where fuel is intensively monitored to provide regional protection to minimise extreme heat and protect life and asset attacks in the occurrence of veldfire.

(ii) The Bushfire Moderation Zone: the land surrounding facilities where fuel is controlled to minimise the rate and intensity of veldfires and support vulnerable properties, in particular from ember attacks in the occurrence of veldfire.

(iii) Landscape Management Zone: an ecosystem in which fuel is managed to reduce the impact of major veldfires, improve the resilience of ecosystems and for other reasons (like forest regeneration and conservation of water catchment).

(iv) Planned Burning Exclusion Zone: the land where you try to avoid organised combustion, mainly because the ecological assets in that zone will not embrace the fire. (Forest Fire Management Victoria, 2019).

2.11.5.1 Big data integration to show veldfire frequency

The veldfire frequency provides information about geographical and climatic dimensions of veldfire events and provides qualitative data to model different climate data to predict exact potential hot spots for veldfires. The study also shows that over the past five years, Australian weekly veldfire rates have risen by 40%, particularly during the summertime, indicating a significant environmental crisis (Dutta, Das and Aryal, 2016).

The goal was to develop a forecasting mechanism that would allow the effect of climate variability on veldfire incidences to be measured within a weekly time scale. Such an approach can be useful in both short and long-term (e.g. simulations of climate change) but is not intended for daily prediction of hot-spots. The accurate weekly fire occurrence estimates from weekly climate data, however, does not automatically suggest that people have little to no effect on the fire incidence of Victoria (Bates, 2019).

Very high temperatures and lack of precipitation have helped the fires to burn big portions of Australian woodland and that made it more difficult for the fire fighters to suppress those veldfires. However with the latest technologies governments are able to predict and characterise those fires guided by the high temperature and lack of rain. (Australian Fire and Emergency Services Authorities Council [AFAC], 2016).

2.11.5.2 Volunteers to reduce veldfire severity

In Victoria, relief efforts rely on thousands of local volunteers putting their everyday lives and work on hold, to fight the blazes. Volunteer fire brigades are widespread across southeast Australia. Recruitments come from towns and agricultural areas, where bushfires in summer months are a part of life (World Economic Forum [WEF], 2020).

The Rural Fire Service of New South Wales claims to be the largest volunteer fire fighting group in the country, with over 72 000 volunteers form 2 000 brigades throughout the state. Among other states, including neighbouring Victoria, volunteer forces are also widespread. This army of unpaid firefighters constitutes the majority of people on the ground tackling the blazes (New South Wales [NSW] Rural Fire Service, 2019).

2.11.5.3 Livestock rescue

In the midst of the fires, the news reported of as many as 1 billion animals dying in the fires, and one zoo worked around the clock to rescue them. Created by conservationist Steve Irwin, the family-run Australia Zoo typically administers lifesaving care to between 6 000 and 8 000 animals per year. But the wildlife hospital personnel have treated tens of thousands of bushfire animal victims including ducks, kangaroos, and koalas (Rosane, 2020).

2.11.5.4 Air rescue operations

New Zealand sent three NH90 helicopters and the Royal New Zealand Air Force crew from across the Tasman Sea to airlift people to safety. The evacuations were provided by the combat engineer division of the Force by ground staff. Coastal towns such as Mallacoota, in Victoria, were engulfed by intruding flames. Despite being hampered by dense smoke, people were ferried out of the way of harm by helicopter flights (WEF, 2020). Confronted with fires of the scale of some smaller European countries, helicopters are a great aid in rapidly reaching stranded people, and in delivering supplies to remote or cut off communities (European Commission. Joint Research Centre, 2009).

2.12 Summary

The literature review was driven by themes developed from the research topic and other topics that were believed to contribute significantly to the understanding of vulnerability in veldfires. The analysis began with definitions of specific concepts, then veldfire vulnerability and growth, finding that many countries were investing vast sums of money in response to veldfire impacts that could also be used to advance development. In cases where vulnerability has a positive functional relationship with disaster risk, the link between vulnerability and disaster risk was reviewed. The most evident factors in Victoria were those contributing to vulnerability, poverty, health well-being, and low rainfall. Some industries in Victoria are more vulnerable to veldfires than others, ranging from forestry, livestock, and rangelands to name a few. Several strategies were indentified for coping with capacity, such as rescuing livestock, supporting vulnerable groups, providing financial support to the affected communities; however, in other parts of Australia, some people had no means to cope with the effects of veldfires, particularly those in agriculture, and were dependent on future aid developments.

Victoria is more reactive than proactive in addressing veldfire disasters, and when it comes to the Bushfire Protection Scheme, there are currently no economic initiatives and minimal compliance measures in place. It has also been found that the consequences of increased veldfires would not only directly impact residents in veldfire-prone areas, but may also impact residents hundreds of kilometres downwind by smoke inhalation. The vulnerability of communities to veldfires increases as the population growth patterns continue, while climate change continues to deteriorate. The assessment of vulnerability in veldfires in various countries and regions are based on certain forms of veldfire prediction models other than the KBDI; while some used quantitative methods and the KBDI, they did not use the commonly used conceptual frameworks for sustainable development as applied in this study with the view of providing intervention measures to policy-makers.

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

The methodology used in this study concentrate on the plan used to conduct the study to describe in detail the research approach, data quality control, reliability and validity, population and sampling techniques, data collection, and ethical consideration. The chapter also presents the methods for modelling veldfire risk, hazard and vulnerability.

3.2 Research approach

The research design is a blueprint and process consisting of measures to be used in the study, from general conclusions to detailed data collection, analysis, and interpretation methods. The approach to be used however is based on the research problem to be discussed (Creswell, 2013). Analysis approaches are classified into three categories: qualitative approach, quantitative method, and mixed-method. The qualitative approach focuses on data collection or generation methods. Nevertheless, to analyse data, it focuses less on empirical methods and uses a comprehensive analysis of secondary knowledge to derive concepts, patterns, and models. Therefore, qualitative data analysis is widely used. It starts with the selection of the study area and builds the theory. The quantitative method uses statistical analysis to equate what is understood regarding scientific facts to what can be learned. (Creswell, 2013). Therefore, the analysis of data using quantitative methods includes either descriptive or inferential statistics to describe the connections between variables (Soiferman, 2010). As Creswell and Clarke observed in (2011), when both qualitative and quantitative methods are implemented in a mixed system, a researcher is allowed to encourage more rigorous analysis. The current study used a quantitative approach to gain a complete statistical analysis to determine the temporal trend patterns of the KBDI values in the study area, the state of Victoria, Australia.

3.3 Data quality control

The primary purpose of protecting the integrity of data is to help recognise systematic errors in the phase of data compilation, whether or not done purposefully (deliberate forgery) (systematic or unintended error) (Whitney, Lind and Wahl, 1998). Quality assurance and quality control are described as two techniques that can protect the integrity of data and guarantee that the results are scientifically accurate and reliable. (Most et al.2003).

3.3.1 Outliers in datasets

An outlier is a result of a group of people in a randomly selected sample that is an abnormal range from other values. In a way, this description puts it to the analyst to decide what is to be called abnormal. (Tuckey, 1977). Until anomalous observations can be selected, it is essential to note normal observations. Two forms of outliers are available: multivariable and univariate. Univariate outliers can be located inside a single space of a function when displaying a value distribution (Quesada, 2017). In an n-dimensional space (of n-features), multivariate outliers can be identified which can be very challenging for the human mind to look at distribution in n-dimensional spaces, that is why we ought to create a network to do it for us (Santoyo 2017).

In the selection, generation, analysis and processing of data, outliers can occur in several ways and hide in certain measurements. Novelties are not those results that are produced in error (Santoyo, 2017). In almost every quantitative discipline, the identification of outliers is of significant importance, (for example economy, cybersecurity, etc) (Cousineau and Chartier, 2010). In the quantitative method, the quality of data is as important as the quality of a prediction. This study will use the Social Science Statistical Package to detect outliers in a dataset. The Social Science Statistical Package is a collection of interconnected software programs in a single package. The core aim of this program is to analyse scientific evidence based on social science. It is used to evaluate, transform, and generate a pattern of characteristics between different data variables.

3.3.2 Homogeneity test in time series

Determination of whether a collection of data is homogeneous is often necessary before any statistical technique is applied to it. It draws homogenous data from a single population (Yozgatlingil and Yazici, 2015). In other words, all external processes which may theoretically influence the data must remain constant over the sample's entire time. Inhomogeneities are caused through a time when artificial changes affect the statistical properties of the observations (Yasici, Yozgatligil and Batmaz, 2012). Depending on the extent of the disruption such changes may be sudden or incremental. Realistically, it is almost impossible to obtain perfectly homogeneous data, because the data will often be affected by unavoidable changes in the area around the observing station (Yasici et al. 2012).

It is common practice to apply statistical methods to climate measurements to check the homogeneity of the time series. This also includes software development. Relative homogeneity tests which review a series of homogeneous stations are preferred to absolute tests which measure only a single position (Karl, Williams and Young, 1986). These comparative experiments, which can be carried out near correlated stations, are much more able to detect inhomogeneities from real climate fluctuations, but they are not able to deal with concurrent changes in experimental routines at both stations (Yozgatlingil and Yazici, 2015). In the case of a low space station density, absolute tests are necessary. The method that will be used to evaluate the homogeneity of the time series is the Pettitt test which is a nonparametric test adapted from the rank-based Mann-Whitney test that allows the point at which the change takes place in a time series to be defined (Pettitt, 1979).

3.4 Population and sampling techniques

The population is the complete collection of cases that meet the criteria defined (Singh, 2018). The attributes of large numbers of individuals, things, or cases are important to social scientists. However, it is difficult for them to test all of these directly, so in these situation analysis studies which rely on sampling, the primary function of sampling is to select the respondents or a small number of items or cases from a much larger set in such a way that the smaller and larger category can be correctly generalized by the examination (Kumekpor, 2002). The number of analytical units that constitute a sample is known as the sample size. Random sampling for this analysis will be easy random sampling. The simple random technique is the form that selects the equivalent chance for each universe to be included or removed from the final sample (Singh ,2013). Eight cities were randomly and strategically selected in the state of Victoria, Australia to cover the whole area and are marked with triangles in Figure 1.1 in Chapter 1.

3.5 Data collection techniques

Data collection is the method by which interesting variables are collected and evaluated in a given systematic way to answer specific research questions, test hypotheses and evaluate finding (United National Conferences on Trade and Development [UNTAD], 2018). For all areas of study, including physical and social sciences, the analysis element of data collection is prevalent. The emphasis should be on maintaining data consistency and reliability. (Whitney et al. 1998).

The National Aeronautics and Space Administration (NASA) has created a data set catalogue produced by South African sponsored research to allow researchers to locate and cite data sets and connect those data sets to scientific literature. The NASA data archive acts not only as a data repository for the reports but also as a registry with data definitions (for example metadata) and information on where and how to access the data (NASA, 2013). In this analysis, climate variability and change focus on data sets that were extracted from NASA's online database to better understand the overall state of Victoria's environment and the physical processes influencing veldfires and to further clarify KBDI inputs that include the latitude of the weather stations, mean annual precipitation, average dry bulb temperature and the last 24 hours of rainfall.

3.6 Data analysis

Analysis means dividing the data into topics, patterns, trends, and relationships that can be controlled. Data analysis aims to determine the various components of one's data by analysing the relationship between principles, structures or variables and to see if there are any patterns or trends that can be identified or isolated or to establish themes in interpretation. (Mouton 2001).

3.6.1 Descriptive statistics

Descriptive statistics require summarising and organising the details to make it easier to understand. Descriptive statistics strive to explain the results, unlike inferential statistics which brings conclusions from the samples to the entire population. Here, we normally describe the details in a report. This generally implies that unlike inferential statistics, descriptive statistics are not constructed on the basis of the probability theory (Kaur, Stoltzfus and Yellapu 2018). Descriptive temperature and rainfall statistics, to explore main trend indicators (mean, median) and measurements of variability (range, standard deviation, variance) will be analysed in this report (Kaur, 2018).

3.6.2 Mann-Kendall Test

The Mann-Kendall test is performed to evaluate whether a time series is monotonic in its upward or downward trend. It does not allow the data to be distributed normally or linearly. It does require auto-relationship (Kendall 1967). This analysis will determine if there are any imminent trends in the input data sets.

3.6.3 Keetch-Byram Drought Index

This drought index was established in 1968 by Keetch and Byram for fire control purposes (Keetch and Byram 1968). The KBDI has been the most commonly used in monitoring and prediction of veldfires, largely due to its simple implementation method compared to other indices that typically need more meteorological data and complex calculations (Garcia-Prats et al. 2015). The KBDI, which conceptually defines the soil moisture deficit, is used as an intermediate quantity evaluating the drought fuel load supply and as a stand-alone index for assessing fire hazard. The index was designed to function in a wide range of climatic and precipitation situations in forest or wildland areas (Johnson and Forthun, 2001). Variations of KBDI and its application to operate in Veldfires have been analysed. Descriptive statistics were used for quantitative analysis, and findings were described by pie charts, frequency distributions, and bar graphs. The KBDI starting values are assumed to be significantly proportional to the percentage of effects on soil moisture expressed as a share of field energy. When calculating KBDI the following (Equation 3.1) is used (Keetch and Byram, 1968):

Equation 3.1

$$dQ = \frac{[800 - Q]\,[0.968 \exp(0.0486T - .830]\,dr}{1+10.88\exp(-.04441R)} \times 10^{-3}$$

Where:

dQ = Drought factor, the unit is 0.01 inches.

Q = Moisture deficiency, the unit is 0.01 inches.

T = Daily maximum temperature, the unit is ^{0}F.

R = Mean annual precipitation, the unit is inches.

dr = Time increment, the unit is 1 day.

The KBDI indicates the level of rainfall needed to restore the soil to the maximum potential of the field. This is a sealed 0–800 unit structure which reflects a 0–8 inch water moisture regime through the layer of soil. At 8 inches of water, the KBDI assumes saturation. Zero is the degree of no moisture shortage and the maximum possible drought is 800. The index number indicates the amount of net rainfall needed to lower the index to zero, or saturation, at any point along the scale. KBDI inputs are latitude at the weather station, mean annual precipitation, average dry bulb temperature, and the last 24 hours of rainfall. Drought relief happens only in situations where rainfall reaches 0.20 inches (called net rainfall). The statistical measures include rising the drought index by the net amount of rain and increasing the drought index by a factor of drought (National Wildfire Coordinating Group.Table 3.1 is the KBDI interpretation according to Abrha and Adhana (2019).

Table 3.1 Keetch-Byram Drought Index interpretation

KBDI (inches)	Risk levels	Description
<99	Very low	Upper soil surface litter are wet and fire potential is very low.
100–199	Low	Upper soil surface litter are moist and do not contribute to fire.
200–299	Moderate	Upper soil surface litter are moderately dry and may contribute to fire.
300–399	High	Upper soil surface litter are dry and contribute to fire intensity.
400–599	Very high	Upper soil surface litter are very dry and fire suppression is a significant.
600+	Extreme	Upper soil surface litter are extremely dry and increase wildfire occurrence.

3.7 Ethical consideration

Informed consent is a legal prerequisite before anyone can take part in research (Gray, Grove and Sutherland, 2016). Permission was obtained from the University of the Free State to perform the report, a copy of the ethical clearance certificate has been attached as Appendix A). Confidentiality is a fundamental concept, though anonymity is one form of preserving confidentiality; no interviews or questionnaires were used in this report. Avoiding harm according to Gray et al. (2016) includes physical, emotional, psychological, and financial risks that may be encountered in research. No persons were involved in this study for data collection, and plagiarism was avoided by the full quoting of sources cited in the report.

3.8 Summary

The chapter outlined the research methodology to clarify that the analysis would examine the quantitative process, ensuring that quality assurance and quality control are defined as two tools that can protect data integrity and ensure that the results are accurate and consistent in scientific terms. The Keetch-Byram Drought Index was used in monitoring and predicting the veldfires to reach the aim and objectives of the study. The methodology will meet ethical guidelines to verify the study findings.

Chapter 4
ANALYSIS AND INTERPRETATION OF DATA

4.1 Introduction

The analysis performed is a quantitative study to investigate different aspects related to veldfires by characterising and predicting those veldfires using the KBDI to provide relevant stakeholders with a full behavioural spectrum of veldfires' for proactive decision making towards building resilience. Data collection was aimed at determining: the trend patterns of the KBDI values in the study area, the likelihood of veldfires in the study area and the return levels of veldfires in the study using the KBDI.

The data collection techniques and data analysis have been discussed in Chapter 3 (3.5 and 3.6). In this chapter, the research presents the empirical result in the study area starting from the pre-data analysis which provides an overview of the structure and characteristics of the input variables of the KBDI. The results were used to formulate recommendations on the conditions of veldfires in the study area to provide intervention steps for policymakers, government authorities and all related private stakeholders.

4.2 Pre-data analysis

Table 4.1 Candidate stations in the study area

Station	Latitude	Longitude
South Gippsland	-38.70	146.05
East Gippsland	-37.33	148.58
Colac-Otway	-38.45	143.59
Glenelg	-37.84	141.45
Murrindindi	-37.27	145.48
Hindmarsh	-36.03	141.72
Loddon	-36.40	143.82
Mildura	-34.21	142.12

Table 4.2 Precipitation descriptive statistics

Station	Observations	Minimum	Maximum	Mean	Standard deviation
South Gippsland	456	0.370	188.750	72.310	39.308
East Gippsland	456	0.410	249.840	64.853	40.932
Colac-Otway	456	0.140	162.830	57.744	32.558
Glenelg	456	0.140	162.830	57.744	32.558
Murrindindi	456	0.210	161.630	60.033	35.827
Hindmarsh	456	0.070	147.060	31.332	23.448
Loddon	456	0.090	178.040	34.030	26.061
Mildura	456	0.010	158.800	22.941	22.061

Tables 4.1 and 4.2 provide the location of the selected stations in the study area and precipitation descriptive statistics, respectively. The average precipitation levels indicate that the top five stations (South Gippsland, East Gippsland, Colac-Otway, Glenelg and Murrindindi) receive relatively higher precipitation than the bottom three stations (Mildura, Loddon and Hindmarsh). This means that the bottom three may encounter the likelihood of fires due to low levels of precipitation. The variations in the standard deviation indicates that South Gippsland and East Gippsland are relatively high as compared to other stations, which means that there is no consistency in precipitation which may result in the possible cause of fire. The minimum indicates that Mildura, Loddon and Hindmarsh receive a very low level of precipitation which could mean that these stations may experience a risk of fire.

Table 4.3 Maximum temperature descriptive statistics

Variable	Observations	Minimum	Maximum	Mean	Standard deviation
South Gippsland	456	9.830	25.730	17.225	3.962
East Gippsland	456	8.320	30.930	18.048	5.935
Colac-Otway	456	10.010	29.200	18.392	4.915
Glenelg	456	10.010	29.200	18.392	4.915
Murrindindi	456	8.390	33.340	19.364	6.469

Hindmarsh	456	11.990	35.780	22.524	6.523
Loddon	456	10.970	36.950	22.677	6.854
Mildura	456	13.750	39.340	25.248	6.747

Table 4.3 on average shows that Hindmarsh, Loddon and Mildura have relatively high temperature, which makes sense because these stations according to precipitation descriptive statistics receive a relatively low level of precipitation. It could therefore mean that due to heat in those particular stations, it might lead to possible fire risk. In terms of standard deviation, the stations at East Gippsland, Colac-Otway, Glenelg, Murrindindi, Hindmarsh, Loddon and Mildura seem to receive the same amount of stressors.

Table 4.4 Precipitation normality test

Station	Shapiro-Wilk	Anderson-Darling	Lilliefors	Jarque-Bera
South Gippsland	0.000	0.006	0.008	0.012
East Gippsland	<0.0001	<0.0001	<0.0001	<0.0001
Colac-Otway	<0.0001	0.002	0.008	0.004
Glenelg	<0.0001	0.002	0.008	0.004
Murrindindi	<0.0001	<0.0001	0.001	0.000
Hindmarsh	<0.0001	<0.0001	<0.0001	<0.0001
Loddon	<0.0001	<0.0001	<0.0001	<0.0001
Mildura	<0.0001	<0.0001	<0.0001	<0.0001

Table 4.5 Maximum temperature normality test

Station	Shapiro-Wilk	Anderson-Darling	Lilliefors	Jarque-Bera
South Gippsland	<0.0001	<0.0001	<0.0001	<0.0001
East Gippsland	<0.0001	<0.0001	<0.0001	<0.0001
Colac-Otway	<0.0001	<0.0001	<0.0001	<0.0001
Glenelg	<0.0001	<0.0001	<0.0001	<0.0001
Murrindindi	<0.0001	<0.0001	<0.0001	<0.0001

Hindmarsh	<0.0001	<0.0001	<0.0001	<0.0001
Loddon	<0.0001	<0.0001	<0.0001	<0.0001
Mildura	<0.0001	<0.0001	<0.0001	<0.0001

Tables 4.4 and 4.5, which is a normality test for both precipitation and maximum temperatures in the study area, aims to provide an overview of the general characteristics of the data sets which can lead to the most appropriate statistical analysis to be used. These tests provide normality across all stations in the study area using the following criteria: Shapiro-Walk, Anderson-Darling, and Lilliesfors were engaged to tell if all stations in terms of precipitation and temperature are normal or not normal. The results were not normal in all the stations, the test shows that time series for all the stations were significant, which means that any statistical test to follow should not be parametric.

Table 4.6 Precipitation homogeneity test

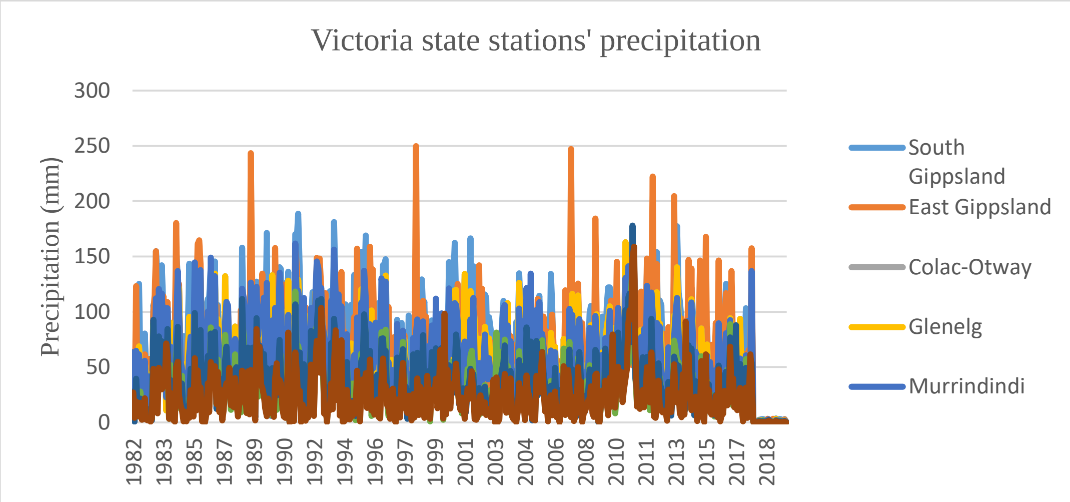
Station	Pettitt's p-value
South Gippsland	0.684
East Gippsland	0.795
Colac-Otway	0.794
Glenelg	0.987
Murrindindi	0.624
Hindimarsh	0.567
Loddon	0.845
Mildura	0.659

Table 4.7 Maximum temperature homogeneity test

Stations	Pettitt	SNHT test	Buishand	Von Neumann
South Gippsland	0.151	0.127	0.086	<0.0001
East Gippsland	0.663	0.240	0.351	<0.0001
Colac-Otway	0.597	0.146	0.348	<0.0001
Glenelg	0.597	0.146	0.348	<0.0001

Murrindindi	0.299	0.293	0.215	<0.0001
Hindmarsh	0.867	0.391	0.667	<0.0001
Loddon	0.983	0.367	0.585	<0.0001
Mildura	0.477	0.495	0.758	<0.0001

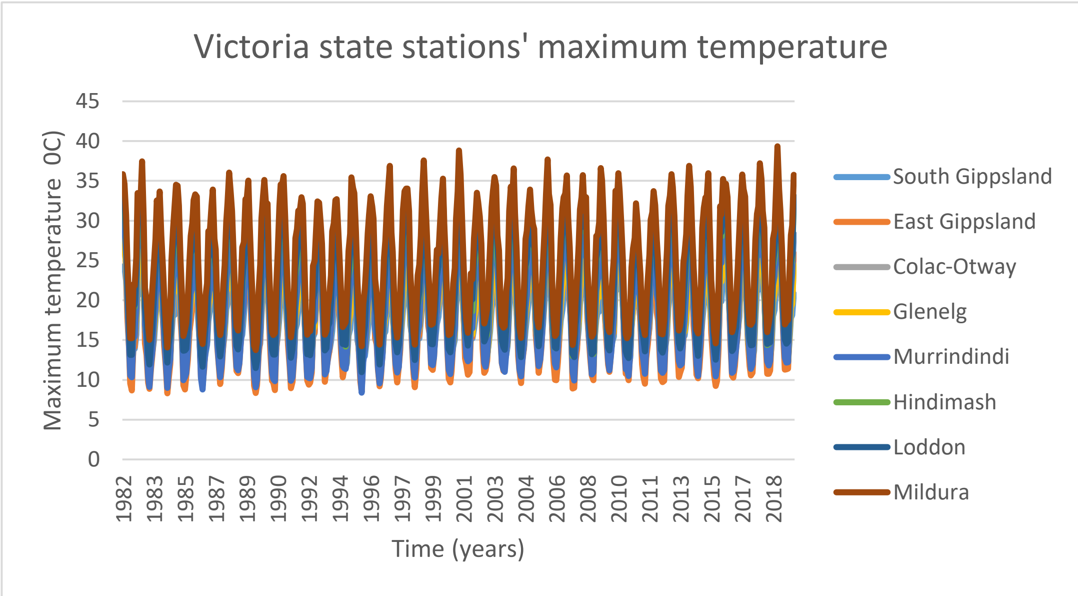
Tables 4.6 and 4.7 indicate a non-parametric homogeneity test for both precipitation and maximum temperature, where the p-values of all the stations in the study area revealed the p-value of above 0.05. This means means that all the data sets of the stations proved to be homogenous, any results derived from these data sets would give meaningful results and would be ready to use in further analysis.



Series/Test	Kendall's tau	p-value	Sen's slope
South Gippsland	-0.145	<0.0001	-0.846
East Gippsland	-0.075	0.017	-0.418
Colac-Otway	-0.147	<0.0001	-0.707
Glenelg	-0.147	<0.0001	-0.707
Murrindindi	-0.155	<0.0001	-0.804
Hindmarsh	-0.106	0.001	-0.318
Loddon	-0.086	0.006	-0.281
Mildura	-0.073	0.019	-0.143

Figure 4.1 Study of precipitation plotting and Mann-Kendall trend test (1982–2019)

Figure 4.1 depicts the plotting of annual precipitation from 1982–2019 for all the stations in the study area. This is an input parameter used in the computation of the KBDI. Virtually, it can be seen that the precipitation data set had several outliers over the years. The outliers had to be removed before further analysis of data to bring about reliable final results. If all the slopes are negative it means, in general the precipitation across all the stations are diminishing which implies that it could be a problem in terms of the dryness of the area which gives way to fire risk. When the p-value is less than 0.05, which is the significance level, it means that there are no statistically significant trends across all stations. However, the results show that the slopes are negative which could be problematic in terms of reliability of the results and that warrant further investigation in this kind of data set.



Series/Test	Kendall's tau	p-value	Sen's slope
South Gippsland	0.066	0.034	0.038
East Gippsland	0.042	0.182	0.036
Colac-Otway	0.047	0.136	0.033
Glenelg	0.047	0.136	0.033
Murrindindi	0.057	0.069	0.049
Hindmarsh	0.037	0.235	0.032
Loddon	0.038	0.229	0.035
Mildura	0.073	0.019	0.143

Figure 4.2: Study of maximum temperature plotting and Mann-Kendall trend test (1982-2019)

Figure 4.2 shows a trend in most of the stations, except for South Gippsland, which has the p-value of 0.034 that is less than 0.05 (the significant value). P-values of all other stations are not significant which means that there is an upward pattern in temperature. When the Sen's slopes show an upward pattern it means the temperature is rising, which could result in moisture decreasing, the place becomes dry and those are some of the factors that increase the risk of fire. South Gippsland seems to be the only place that could be safe as far as the temperature is concerned.

4.3 Data analysis

Table 4.8 Keetch-Byram Drought Index correlation matrix: Spearmans

Variables	South Gippsland	East Gippsland	Colac-Otway	Glenelg	Murrindindi	Hindmarsh	Loddon	Mildura
South Gippsland	**1**	0.226	0.225	-0.002	0.061	-0.150	-0.236	-0.056
East Gippsland	0.226	**1**	-0.188	0.025	0.167	-0.089	0.012	0.051
Colac-Otway	0.225	-0.188	**1**	0.007	0.372	-0.133	-0.179	-0.044
Glenelg	-0.002	**0.025**	0.007	**1**	0.402	0.164	0.095	0.175
Murrindindi	0.061	0.167	0.372	0.402	1	0.116	0.126	0.225
Hindmarsh	-0.150	-0.089	-0.133	0.164	0.116	**1**	**0.687**	0.336
Loddon	-0.236	0.012	-0.179	0.095	0.126	**0.687**	**1**	0.288
Mildura	-0.056	0.051	-0.044	0.175	0.225	0.336	0.288	**1**

(Values in bold are different from 0 with a significance level alpha=0.05)

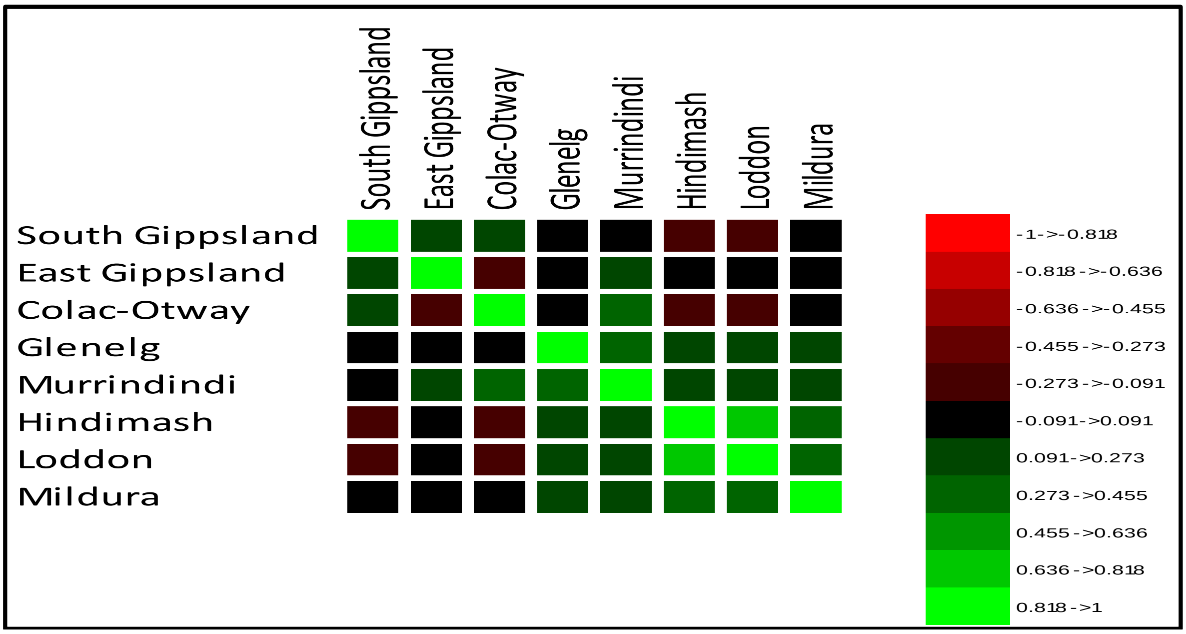
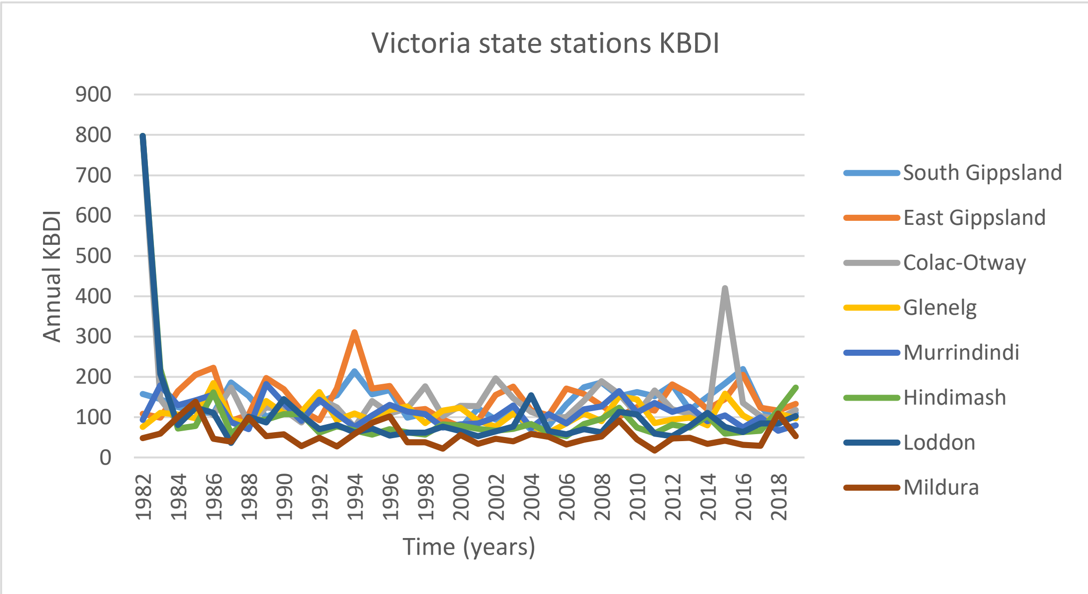


Figure 4.3 Image of the correlation matrix: Spearmans

Table 4.8 and Figure 4.3 show that there is a correlation matrix. The results show that all other stations are unique, except for Loddon and Hindimarsh which present a correlation coefficient of 68%. Anything less than 50% is weak, therefore it indicates that both stations behave similarly as far as exposure to veldfires is concerned. This correlation matrix helps us to know exactly where to channel the resources in the study area.



Series/Test	Kendall's tau	p-value	Sen's slope
South Gippsland	0.023	0.847	0.125
East Gippsland	-0.045	0.699	-0.221
Colac-Otway	0.015	0.904	0.106
Glenelg	-0.061	0.595	-0.193
Murrindindi	-0.163	0.147	-0.610
Hindmarsh	-0.061	0.595	-0.186
Loddon	-0.163	0.147	-0.568
Mildura	-0.139	0.217	-0.334

Figure 4.4 Study area's Keetch-Byram Drought Index plotting and Mann-Kendall test

Figure 4.4 shows the plotting of the KBDI across all stations on annual basis and results in a non-parametric Mann–Kendall trend test which showed no trend in the series with non-significant p-values of over 0.05. Therefore, it means that there is no vulnerability to veldfires in the study area.

Table 4.9 Frequencies in Keetch-Byram Drought Index classes

KBDI Classes	Risk level	South Gippsland	East Gippsland	Colac-Otway	Glenelg	Murrindindi	Hindmarsh	Loddon	Mildura
200-299	Moderate	2	3	1	0	0	1	1	0
300-399	High	0	1	0	0	0	0	0	0
400-499	Very High	0	0	0	0	0	0	0	0
600+	Extreme	0	0	0	0	0	0	0	0

Table 4.9 shows the frequencies that are 200 and higher to demonstrate the possibility of veldfires in the study area. The KBDI class frequency reveals two stations with relatively high values, namely South Gippsland and East Gippsland. Even though the numbers are relatively high the risk level is still moderate. The results further shows East Gippsland as the only station which falls in the high category, and the other stations shows no risk according to the KBDI class frequencies. Therefore, the risk level in the study area is moderate to less.

Table 4.10 Keetch-Byram Drought Index probabilities

KBDI Classes	Risk level	South Gippsland	East Gippsland	Colac-Otway	Glenelg	Murrindindi	Hindmarsh	Loddon	Mildura
200-299	Moderate	2/38	3/38	1/38	0	0	1/38	1/38	0
300-399	High	0	1/38	0	0	0	0	0	0
400-499	Very High	0	0	0	0	0	0	0	0
600+	Extreme	0	0	0	0	0	0	0	0

Table 4.10 shows the probability of the stations to reach the risk level of moderate. The results depicted in a 365 cumulative 38-years thimespan shows that South Gippsland scored 2/38 = 5%, East Gippsland 3/38 = 7.8%, Colac-Otway 1/38 = 2.6%, Hindmarsh1/38 = 2.6%, and Loddon 1/38 = 2.6%. For East Gippsland to reach the risk level of high is 1/38 = 2.6%. The probability to high must be anything above 50%, therefore, the probability of the stations to reach moderate is very low let alone from high to extreme is 0% chance which means the study suffers nothing in general.

Table 4.11 Keetch-Byram Drought Index levels (inverse probabilities)

KBDI Classes	Risk level	South Gippsland	East Gippsland	Colac-Otway	Glenelg	Murrindindi	Hindmarsh	Loddon	Mildura
200-299	Moderate	19 years	13 years	38 years	0	0	38 years	38 years	0
300-399	High	0	38 years	0	0	0	0	0	0
400-499	Very High	0	0	0	0	0	0	0	0
600+	Extreme	0	0	0	0	0	0	0	0

Table 4.11 shows the return levels of risk to reach moderate over a certain time and the results shows that for South Gippsland to reach the risk level of moderate will take 19 years, East Gippsland 13 years, Colac-Otway 38 years, Hindmarsh 38 years, Loddon 38 years and it will also take 38 years for East Gippsland to reach risk level of high. Therefore the resources need to be channelled to East Gippsland and South Gippsland because they are lowest in terms of the return levels. After 13 and 19 years, mitigation strategies must be employed to minimise those moderate risk levels in those particular stations, because even though they are moderate, they could be catastrophic if they happen more frequent. After every 38 years East Gippsland may experience a high risk level, therefore, the resources need to be made available to minimise the risk which may be catastrophic.

4.4 Summary

This chapter looked at the empirical results in the study area starting from the pre-data analysis which provided an overview of the structure and characteristics of the input variables of the KBDI. The researcher used different methods for pre-analysis of data, namely descriptive statistics, normality tests, trend tests and plotting. The results derived from those tests gave meaningful results and were ready to be used for further analysis in the study area. The KBDI plots and trends were used to determine the trend patterns of the KBDI values in the study area and the categories (return levels) were analysed to determine the likelihood of, and the return levels of veldfires in the study area. The researcher deals with the conclusion and recommendations in the next chapter.

Chapter 5
SUMMARY, CONCLUSION, RESULTS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Introduction

This chapetr gives the summary, conclusion and recommendations of the study. The conclusion is made based on the quantitative analyses performed and the literature review carried out. The results were summarised according to the study's objectives.

5.1.1 Summary of the study

The 2019 Victorian veldfires were far reaching. Farmers, fishers, and forests, along with rural regional and urban communities faced devastating veldfire events during summer season. In addition to the dangers of an active veldfire smoke, ash and chemicals used to treat fires negatively affect air and water quality. A 38 year-long time series were obtained from an online NASA data base. The empirical results in the study area starting from the pre-data analysis which provided an overview of the structure and characteristics of the input variables of the KBDI. Different methods for pre-analysis of data, namely descriptive statistics, normality tests, trend tests and plotting were used. The current study therefore aimed at characterising and predicting veldfire risk in the study area using the Keetch-Byram drought index and to provide intervention measures for policymakers, government authorities and all relevant private stakeholders about the conditions of veldfires in the study area.

5.1.2 Results

The empirical result in the study area starting from the pre-data analysis provides an overview of the structure and characteristics of the input variables of the KBDI. The normality test was deployed using the following criteria: Shapiro-Walk, Anderson-Darling and Lilliesfors were engaged, the results for both precipitation and temperature came out not normal. A homogeneity test for both precipitation and temperature was deployed using a non-parametric Pettitt's test and the results revealed a p-value that are above 0.05 which means that all the data sets of the stations proved to be homogenous.

5.1.2.1 Results based on the objectives of the study

The results for objective number one were covered by the results of the KBDI plots and trends. Objectives three and four were covered by the results of the KBDI categories (probabilities and return levels).

Objective 1: To determine the trend patterns of the KBDI values in the study area. Results revealed that the plot and precipitation of the Mann-Kendall trend test for the majority of the stations have a p-value that is less than 0.05 (significant value). The plot and the temperature in the Mann-Kendall test revealed p-values that are above 0.05.

Objective 2 and 3: To determine the likelihood of veldfires in the study area and to determine the return levels of veldfires in the study area using the KBDI. The KBDI class frequency revealed two stations with relatively high values, namely South Gippsland and East Gippsland. Even though the numbers are relatively high, the risk level is still moderate. The results further indicates that East Gippsland is the only station which is in the high-risk category, and the other stations showed no risk according to the KBDI class frequencies. Therefore the risk level in the study area is moderate to less. The KBDI probabilities indicates the probability of the stations to reach the moderate risk level, and the results depicted is of cumulative 38 years. South Gippsland scored 2/38 = 5%, East Gippsland 3/38 = 7.8%, Colac-Otway 1/38 = 2.6%, Hindimarsh 1/38 = 2.6%, and Loddon 1/38 = 2.6%. For the East Gippsland to reach the risk level of high 1/38 = 2.6%. The KBDI return level revealed that for South Gippsland to reach a moderate risk level it will take 19 years, East Gippsland 13 years, Colac-Otway 38 years, Hindmarsh 38 years, Loddon 38 years and it will take 38 years for East Gippsland to reach a high-risk level.

5.2 Conclusion

The study found during the disaster that happened in Victoria, seems to be one of the rare cases as the statistics and the analysis in the study area show to be under uniform conditions. These uniform conditions have been revealed by the results in the KBDI plot and the Mann-Kendall test indicates that there is nothing that shows the study area is moving towards trouble. The condition of the vegetation seems to be constant. What happened was the human factor or negligence in the policies and regulations and of the people who do not obey the law. With this low probability and 13–38 year-long return level, the study found the area less prone to fire risks detrimental to the environment, animals, and human beings The analysis of the literature on the effect of fire on the environment indicates that veldfires on erodable land can exacerbate erosion. Extremely hot veldfires can obliterate the business value of the wood, therefore prescribed burns have proved to be the most efficient way to minimise the risk of woodland and agricultural fires. Controlled burns have been shown to decrease the occurrence of veldfires on the agricultural land. Veldfire management policies when properly implemented can be beneficial to forests, agriculture, and pasture management.

5.3 Recommendations

5.3.1 Researchers

This study, therefore, recommends that other researchers look at studies that will investigate the human factors. The study did not concentrate on the lower temporal scales which are the seasons and monthly KBDIs, the study only concentrated on the annual KBDI. If this study had concentrated on the lower time scales, it might have found something different. Therefore, this study recommends that the next person do a similar study, but then concentrate on the lower temporal scales as well as the human impact on the study area.

5.3.2 Lawmakers

The study only focused on the environmental factors that caused the spread of veldfires in the study area. It did not take into account the behavioural factors of human beings. The probability of veldfires takes time to return at this particular level. The only way to eliminate them is to practice proper management of fires by making fire breaks, retrofit houses, as well as preparedness planning, that must be drawn up and obeyed by the communities at risk. Policy-makers must ensure there is enough funding for mitigation strategies and to boost researchers to come up with the best possible solutions. The vegetation that is removed from the woodland can be used as a source of income which will fund mechanisms that will prevent veldfires. Climate change has proved to be one of the major causes of veldfires, therefore more funding should be channeled towards the causes of climate change.

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APPENDIX A

Ethical Clearance Certificate

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS UV

GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

05-Aug-2020

Dear Mr Toyi Diphagwe

Application Approved

Research Project Title:
Strengthening resilience in agricultural projects by characterisation of Veldfires using Keetchy-Byram drought index: A case of Victoria a state in Australia

Ethical Clearance number:
UFS-HSD2020/0809/0508

We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Approved – desktop study

Yours sincerely

Dr Adri Du Plessis
Chairperson: General/Human Research Ethics Committee

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APPENDIX B
Confirmation of Editing and Proofreading

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24 January 2021

CONFIRMATION OF EDITING AND PROOFREADING

I hereby confirm that I have done the technical layout and language editing for the following dissertation:

Student:	Toyi Maniki Michael Diphagwe
Title:	Strengthening resilience in agricultural projects by characterisation of veldfires using Keetch-Byram Drought Index: A case of Victoria State in Australia
Degree:	Master in Disaster Management
Department:	Disaster Management Training and Education Center for Africa, University of the Free State

My work for the student included the technical layout of the document, as well as language editing for grammar, punctuation, spelling, and sentence structure. I tried to keep as much as possible of the student's own writing style while making sure that the student's intended meaning was not altered in the editing process. I also checked the list of references making sure that dates, spelling, and names used in the text are consistent with those listed in the reference list.

I have a B.Bibl. (Hons.) Degree and have been working as a cataloguer and librarian for 29 years. I am an expert in the field of bibliographic information and resources. I have also completed a 10-week Copy-Editing course at the University of Cape Town.

Disclaimer: The ultimate responsibility for accepting or rejecting the changes and recommendations rests with the student and I cannot be held responsible for any layout or language issues that might have emerged as a result of subsequent amendments to the text.

Yours sincerely,

Nicolene Barnard