The occurrence and impacts of destructive hail/hailstorms in South Africa based on newspaper reports: 1900 to present

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DECLARATION

I, Inga Matshabane, declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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20 day of May 2023 at East London

ABSTRACT

Hail is of one the most destructive forms of precipitation. A single hailstorm has the potential to cause extensive damage to crops, livestock, property and infrastructure, and in some cases may even cause human fatalities. This dissertation aims to examine the occurrence and consequences of hail/hailstorm-related events and disasters in South Africa, as reported in newspapers since the beginning of the 20th century. The main objectives are to determine and map the areal coverage (spatial and temporal patterns) of destructive hail/hailstorms in South Africa and identify potential changes over time. Documenting the consequences and human responses due to destructive hail/hailstorms also form part of the objectives.

South African hailstorms mostly covered the central and eastern parts of the country (i.e., Free State, KZN, Gauteng as well as some parts of the North West and Eastern Cape Provinces; Limpopo is also included as the eastern part of the country even though it is usually described as the northern part), with most of these destructive hail events reported in Gauteng. The provincial variations in hail day coverage are affected by elevation and latitude. The spatial dynamics of population density affect the number of reported hail events reported in newspaper articles. The hail events in each province differs in seasonal and diurnal occurrence, with most of the destructive events occurring in November between 15:00 and 18:00, accompanied by strong winds.

Hail damage was mainly caused by hailstones the size of tennis balls, affecting crop and orchards, which reveal the areal extent of hail damage. Sheep, birds, and poultry are reported to be the most impacted animals by hail. Findings also show that roofs and windows (both in buildings and transport) are the most damaged by the destructive hail events. Newspaper articles also reported on human fatalities and injuries directly and indirectly during some hailstorm events. The damage is controlled by high wind speeds, the angle of hailstone impact and the weight of the hailstones.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. BACKGROUND

1.1 INTRODUCTION

Hail is a common occurrence in many parts of the world and has apparently become worse in its damaging effects through recent centuries (Olivier, 1990; Changnon *et al*., 2009). One reason for this is that the earth has become more populated with widespread land-use vulnerable to hazards such as hail (Buckley et al., 2010). This means that when a severe weather phenomenon occurs (i.e., hailstorms), more property is likely to be damaged than in a more sparsely populated and inhabited world (Botzen *et al*., 2010). Hail risk assessments and risk mapping are important for the prevention and mitigation of hail hazards for stakeholders that may be affected (Cică *et al*., 2015). Thus, studies on hail and its characteristics have been undertaken in many parts of the world for many different reasons such as insurance, agricultural purposes, modelling, aviation, and engineering (Allen and Allen, 2016).

Hail has the potential to cause extensive damage to crop, livestock, property, and infrastructure, and in some cases even causes human fatalities (Changnon Jr., 1977; Pyle, 2006; Martins *et al*., 2017). Through ongoing research, hailstone growth is initiated from convective thunderstorms that require specific conditions to form, such as moisture, a strong updraft, large super-cooled liquid water content, variable winds, freezing temperatures at lower levels of storm clouds and a sufficient lifespan (Pidgeon and Fischhoff, 2011; Punge and Kunz, 2016). This formation normally takes place over continental temperate and subtropical regions, and occasionally in the tropics (Smith *et al*., 1998). In southern Africa, hail commonly occurs in the summer rainfall regions (Carte and Held, 1978; Butgereit, 2014). Figure 1.1 illustrates hail 'hot spot' regions globally, further highlighting the geographic environments in which hail most frequently occurs (Prein and Holland, 2018). Damage amassed by hail is mainly determined by characteristics attributed to hail size, the number of hailstones per unit area and the strength of the accompanying wind (Bal *et al.*, 2014).

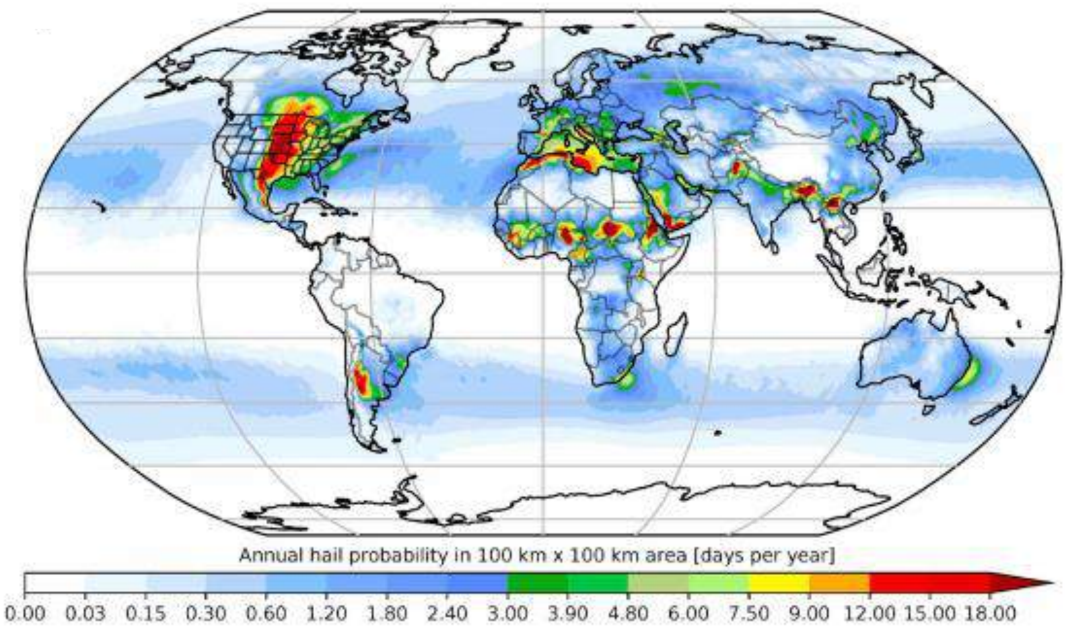


Figure 1.1: *A global hail hazard map highlighting hail hotspots (Prein and Holland, 2018).*

"Hail hotspots" have been determined through various techniques and studies, such as documentary (which includes written sources) and instrumental data, which also includes radar and microwave information (Changnon, 1999; Visser and Heerden, 2000; Wouters *et al.,* 2019; Fluck *et al.,* 2020; Brook *et al.,* 2021). Hail data inventories may be kept by national weather offices or be held privately by scientific institutes or scientists, primarily for the use in hail research. Several hail studies have included hail risk maps (e.g., Webb *et al.,* 2008; Prein and Holland, 2018; Sills and Joe, 2019). Even when the climatology of hail is developed for a country, such studies usually tend to focus on hotspots. Such climatologies include "*Climatology of hail in Argentina*" (Mezher *et al.,* 2012) and "*Climatology of destructive hail in Brazil*" (Martins *et al.,* 2017), "*Climatology of Hail in Central Europe*" (Suwala and Bednorz, 2013). Such studies have presented theories as to the different occurrences of hail associated with different environments. This is also evident from Figure 1.1, where three latitudinal zones of common hail occurrence are portrayed; namely between 25-40 degrees in the Southern Hemisphere, around the equator and more broadly in the Northern Hemisphere (with the "*Hail Alley*" in the United States of America prominently showing) and hail occurring in mountainous regions such as the Himalayas and the Andes (Mehzer *et al.,* 2012; Negi *et* *al.,* 2017). The climatologies help closely examine the affected areas and help provide reasons for such hail distribution.

Hail is considered a complex extreme weather phenomena in the atmosphere and due to the nature of its occurrences, it cannot be reliably detected by traditional weather observation networks (Martins *et al*., 2017). Thunderstorm studies are also critical when studying hail, as hail is generally accompanied by such storms (Rae *et al.*, 2018). Evidence for this is noted through hail occurrence being mentioned, by default, in many scientific papers studying thunderstorms (e.g., Pyle, 2006; Butgereit, 2014; Moyo and Nangombe, 2015; Masereka *et al.,* 2018, Sills and Joe, 2019). Hailfall is one of the ways in which thunderstorms are classified, such that a thunderstorm that includes hail is characterised as a "severe" thunderstorm (the correlation of hail to thunderstorms is highlighted in Figure 1.2 and calculated to 0.63) (Prein and Holland, 2018).

Many unprecedented severe weather events have been associated with recent accelerated climate change (e.g., Seneviratne *et al*., 2021). Climate change has either strengthened or weakened some climatic systems, impacting their frequency and intensities around the world (Campbell *et al.,* 2016). Investigating the changes associated climate-related disasters as well as their newfound capabilities, will help better establish and understand their impacts, and thus help improve measures already put in place to lessen their impacts on the environment and society (Watkins and Bazerman, 2003).

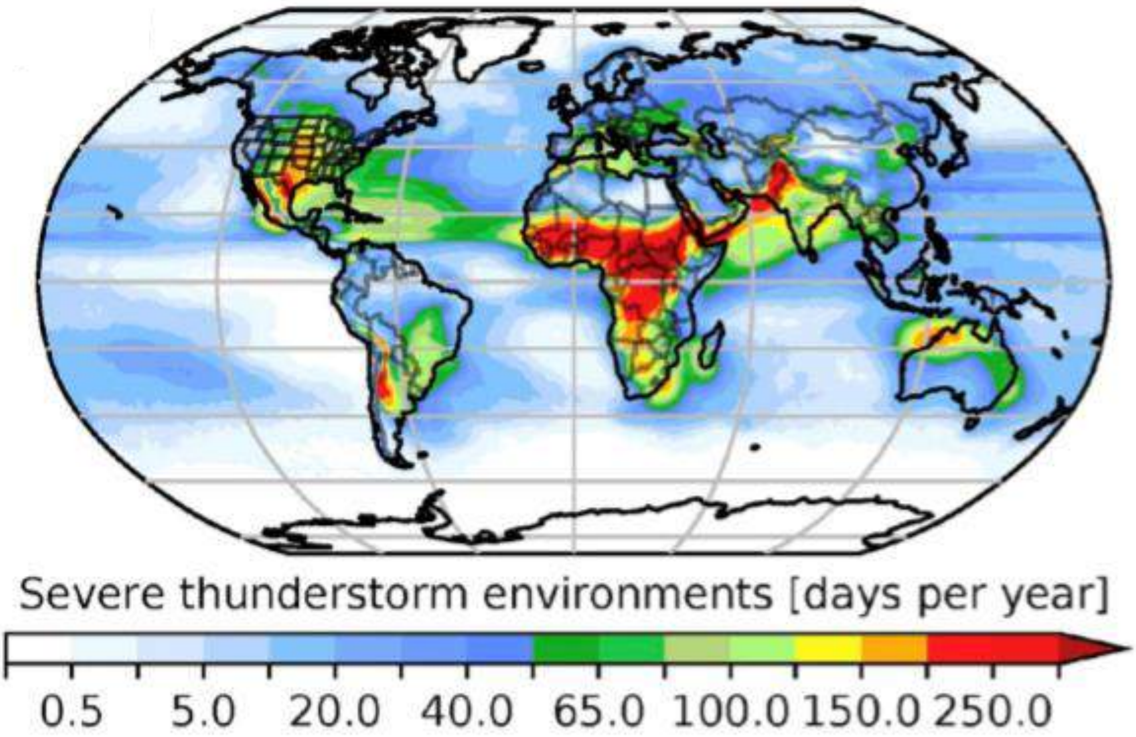


Figure 1.2: *A global severe thunderstorm hazard map with global hail hotspots (Prein and Holland, 2018).*

Most of the social and economic costs associated with climate change result from shifts in the frequency and severity of extreme events (Huber and Gelledge, 2011). For example, one of the largest hailstorm damages cost $500 000 (now just over R400 000 million) in 1928, and by 2013 this amount had reached R1.4 billion in the South African Highveld region (Rand Daily Mail, 19 October 1928; Davis-Reddy and Vincent, 2017). However, it would not be accurate to say that all weather changes and costs are due to climate change. Due to the destructive nature and the costs associated with hailstorms, several studies have been conducted on hail events in different parts of the world, as summarised in Table 1.1.

Table 1.1: *Seasonal geographic distribution of hailstorm across the world (Martins et al., 2017).*

Region	Country	Season	Authors
North America	United States	Spring/summer	Lemons, 1943; Kelly et al., 1985; Kerschner, 2011; Cintineo et al., 2012; Allen et al., 2015
	Canada		Paul, 1980; Admirat et al., 1985; Etkin and Brun, 1999
Europe	Finland		Tuovinen et al., 2009; Saltikoff et al., 2010; Tuovinen et al., 2015
	Great Britain		Webb et al., 2001; Webb et al., 2009
	Germany		Gudd, 2003; Deepen, 2006; Suwała, 2013
	Switzerland		Admirat et al., 1985
	Czech Republic		Brázdil et al., 2016
	Castilha-La Mancha - Spain		González Martín, 2010
	Lleida - Spain		Aran et al., 2011
	Ebro Valley - Spain		García-Ortega et al., 2011
	Valencia - Spain		Cantos, 1994; Cantos et al., 1998
	France		Dessens, 1986; Fraile et al., 2003; Berthet et al., 2011; Merino et al., 2014b
	Northern Italy		Morgan, 1973; Giaiotti et al., 2003; Manzato, 2012
	Continental Croatia		Počakal et al., 2009
	Romania		Apostol and Machidon, 2009; Lungu et al., 2010
	Serbia		Ćurić and Janc, 2015
	Moldavia		Apostol and Machidon, 2011
	Bulgaria		Simeonov, 1996
	Macedonia		Dimitrievski, 1983
	Northern and Central Greece		Dalezios and Spanos, 1995; Sioutas et al., 2009
	Turkey		Kahraman et al., 2011; Kahraman et al., 2016
Oceania	Australia		McMaster, 2001; Schuster et al., 2005
Africa	Transvaal - South Africa		Admirat et al., 1985
Asia	Northern and Northwestern China		Zhang et al., 2008
	Southern China	Winter/spring	Xie et al., 2010
	India		Frisby and Sansom, 1967; Nizamuddin, 1993
	Myanmar and Easthern Pakistan		Frisby and Sansom, 1967
	Iran		Farajzadeh and Mostafapoor, 2012; Banafsheh et al., 2016
South America	Northeastern Argentina*		Mezher et al., 2012
	Paraguay		Frisby and Sansom, 1967
	Tropical Brazil		Frisby and Sansom, 1967
	Southern Brazil		Berlato et al., 2000; Marcelino et al., 2004; Iliine et al., 2010
	Southern Brazil		This study

Table 1 also highlights the notion that most research on hail/hailstorms has been undertaken in the northern hemisphere, which coincides with the majority of such events recorded in that hemisphere. The United States of America is said to be the most affected by hail (Bal *et al.*, 2014), followed by countries such as Kenya which has a world-record of 132 hail days per annum (Gibbs, 2016); France (Berthet *et al.,* 2011); Australia (Tucker, 2002; Punge and Kunz, 2016) and India (Bal *et al.,* 2017). Any improved understanding of the occurrence of such weather events, including hailstorms, is of value as it may help lower potential risk. There has not been much focus on hail in recent South African climate studies, although it was a topic that received some attention in the recent past (e.g., Carte and Held, 1978; Admirat *et al.,* 1985; Mader, 1986; Olivier, 1990). Past studies were focussed on the north-eastern South African Highveld, given that hailstorms are most frequent in this region (Simpson and Dyson, 2018).

South African hail studies began in the 1960s with a detailed description of spatial and temporal hail patterns (Olivier, 1990). As hailstorm research progressed, different methods were used in studying the frequency and characteristics of hail (Roos and Carte, 1973; Held, 1974; Carte, 1977; Roos, 1978, 1980, 1981), hail paths and types of storms associated with hail (Tyson, 1986; Held, 1978; Mader, 1979; Kelbe, 1984), radar characteristics (Held, 1978; Mader, 1979) and hail trajectories (Carte and Held, 1978; Admirat *et al.,* 1985; Olivier, 1990). Besides these mentioned studies, South Africa has had several hail research programmes conducted by the CSIR, which included information from observers to study hail dynamics and hailstone growth as early as 1962, and the Bethlehem Weather Modification Experiment (Olivier, 1990; Pyle, 2006). A comparative study between Switzerland, Canada, and South Africa, has shown that South Africa has the greatest absolute number of hail days per year (Admirat *et al.,* 1985). A further study comparing hail events between Alberta (Canada) and South Africa, found similar results and classified severe hailstorm episodes as an episode that has at least one day of maximum hail size larger than 33mm in Alberta and 31mm in South Africa (Smith *et al.,* 1998). This points to the fact that hail events are variable through time and space. Hail as a hazard is important to forecast ahead of time, which has become possible through the availability of refined models. Hail forecasting, however, was already achieved through extensive and detailed data availability during pre-modelling times. Recently, studies investigating hail events in South Africa have been for insurance purposes or for individual hail events (e.g., Piketh and Burger, 2014; Davis-Reddy and Vincent, 2017; Simpson and Dyson, 2018).

The study of natural hazards from natural archives is of importance as it helps with projecting future risk and finding ways to manage a disaster (Pfister *et al.,* 2002). While hail is a very common phenomena in South Africa, associated mainly with summer rainstorms, the more noteworthy events which have one or more negative impacts on the environment and/or society are published in newspapers- it is these types of events that are of interest, and which will be examined in this project. This MSc research project specifically examines the occurrence and consequences of hail or hailstorm related events and disasters in South Africa, as reported in newspapers since the beginning of the 20th century. Newspapers are rich in qualitative and quantitative observations, suitable for the reconstruction of temporal and spatial patterns of weather and climate, as well as climate-related natural hazards (Nash *et al.,* 2019). Similar studies of this nature have been undertaken using other archive data such as meteorological data, letters, and agricultural reports (del Rosario-Prieto and Herrera, 2009; Pfister and White, 2018). Authors have used a variety of other written documents such as colonial and missionary records, diaries, and ship logs, to name a few (e.g., Allan *et al.,* 2016; Mahony and Endfield, 2018). Not only do such written reports document past weather, but also societal consequences and responses. The increasing impacts of 'extreme' weather events that have influenced people in the past and how these events may continue to influence future responses, has become a research theme of global interest (Allan *et al.,* 2016).

1.2 THE ROLE OF MEDIA IN REPORTING NATURAL HAZARDS

Hazards can be both naturally and anthropologically induced; both these are reported in the mass media and will both be discussed for the purpose of their role in mass media (Houston *et al*., 2012). There are different ways that the media operates during natural hazards and disasters and these processes may affect the public's understanding of the disaster event (Sood *et al.,* 1987, Perez-Lugo, 2004). Natural hazards and natural disasters differ in that natural hazards are defined as a "*natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage"* (UNISDR, 2009, p.20). A natural disaster can be defined as an event in which more than 10 people were killed or more than 100 people were affected (Sawin *et al*., 2023).

Disaster stories tend to receive high audience interest, but this may diffuse very rapidly (Sood *et al.,* 1987). The media can also tend to over-report or sensationalise stories, which can lead to hazard risks being amplified. The media may also shift into higher gear, searching for newer news on the topic, or they can generate news on the topic by reporting comparative incidents and reiterating past similar incidents (Goltz, 1984; Vasterman *et al.,* 2005). The implications of such a trend on reporting natural hazards can range from impacting the tourism industry (whether misrepresented or accurate, results in economic losses for affected area) to shifting attention away from emergency relief and response (Walters *et al*., 2016; Clark-Ginsberg and Roberts, 2020).

The media routinely covers pre-scheduled and anticipated disasters, but these tend to be different when natural disasters and crimes are covered because these tend to not be anticipated (Sood *et al.,* 1987). There is a framework, however, that the media uses to achieve a well-structured communication during a disaster, and it includes the following (Rattien, 1990; Miles and Morse, 2007):

- Pre-problem stage
- Alarmed discovery and euphoric enthusiasm
- Realizing the cost of significant progress
- Gradual decline of intense public interest
- A post problem stage.

These stages of reporting a disaster may vary depending on the author but follow similar steps. Action taken by disaster management authorities also depends on the stages of reporting a disaster mentioned above (Scanlon *et al.,* 1985; O'Connell and Mills, 2003; Perez-Lugo, 2004; Houston *et al.,* 2012; Lucchini *et al.,* 2017). Disasters can sometimes cut out communication, degrading the service that can be provided to the affected areas, thus media coverage has the ability to minimise the discourse during these disaster events (Sood *et al.,* 1987; Miles and Morse, 2007). These stages can affect the number of newspaper articles available, as also the type of information that could be extracted.

Recently, the use of social media during disasters has started to receive scholarly attention from various disciplines (O'Connell and Mills, 2003; Murthy and Longwell, 2013; Athanasis *et al.,* 2018; Dong *et al.,* 2018; Yang *et al.,* 2019). Social media created a communication channel whereby individuals are being highly engaged as producers and disseminators on information (O'Connell and Mills, 2003). With social media rapidly evolving, it has become the fourth popular source to access emergency information (Lindsay, 2011). The downside to this, however, is the fact that those published stories are usually not verified and can be very misleading, yet many provide a platform for rapid detection for natural disasters, situational awareness, and relief coordination (Crow *et al.,* 2017). In a quality-controlled environment, social media can serve as a substantial resource in natural disaster verification (Blair and Leighton, 2012; Simpson and Dyson, 2018). This, however, cannot replace traditional media, as these are needed from when studying timelines that go beyond the social media became a platform for disaster awareness (Miles and Morse, 2007; Barnes *et al.,* 2008).

Past-published studies have chosen specific disasters and examined how the media covered news on such disasters, how the media depicted the authority's response and how the audience received the news (Sood *et al.,* 1985; Vasterman *et al.,* 2005). Ali (2014) provides a well-rounded summary of the role media plays during natural disasters, discussing the myths and benefits of media post-disaster. The media's primary role in reporting on disasters is to inform on notable events that have caused damage or harm to its surroundings (Barnes *et al.,* 2008). For instance, there are a number of studies that focussed on Hurricane Katrina and how the media covered different aspects of this disaster (Tierney *et al.,* 2006; Littlefield and Quenette, 2007; Barnes *et al.,* 2008). Such studies typically undertake a keyword search on the selected newspaper and then proceed to categorise them based on their objectives (Miles and Morse, 2007). From this, the main categories would include recovery and response as well as mitigation and preparation (Miles and Morse, 2007; Barnes *et al.,* 2008). The newspapers are also compared across national and local newspapers, to study the influence that media has on the public (Vasterman *et al.,* 2005). In South Africa, such studies have apparently been inadequate from a governance perspective (Ramluckan, 2016).

Disasters in the media are often treated as important topical stories; however, questions on which news or aspects of the disasters deserve such attention, is a key question when studying disasters through media outlets (Sood *et al.,* 1987). Studies of disaster risk have shifted from being purely hazard-based to including a social dimension which includes socio-economic factors (Noy and

Yonson, 2018; Penduzzi, 2019). The media prompts public awareness and concern on the assumption that the media concentrates on a few issues and some subjects are more important than others (Miles and Morse, 2007; Barnes *et al.,* 2008). Through the analysis of Hurricane Katrina, the media coverage was 78% recovery and response, and 7.89% on mitigation and preparation (Barnes *et al.,* 2008). Even though improved telecommunications technologies have been the best way to apply the use of science and engineering to mitigate natural hazards, media crisis and risk communication has to complement it (Rattien, 1990; Houston *et al.,* 2012).

1.3 RATIONALE

Hail is one of the most destructive forms of precipitation. A single hailstorm can cause damage ranging from millions to billions in any currency over a densely populated or cultivated area (Cică *et al.,* 2015; Picak *et al.,* 2019). Figure 1.3 provides an index of historical hazard events and indicates that South Africa is primarily exposed to natural hazards of a weather-related origin (Bruwer *et al*., 2017). The most frequently occurring sudden onset of hazards are related to flooding, followed by wind, hail, snow and heavy rain. It should also be highlighted that these hazards can trigger a chain reaction, for example, heavy rains/thunderstorms can be accompanied by hailstorms, which have the tendency to block storm drainage, increasing flood damage, or may cause landslides, which themselves are hazards. Therefore, people must be alerted of other (associated) potential hazards when a particular weather hazard is expected (South African Weather Service Annual Report, 2018).

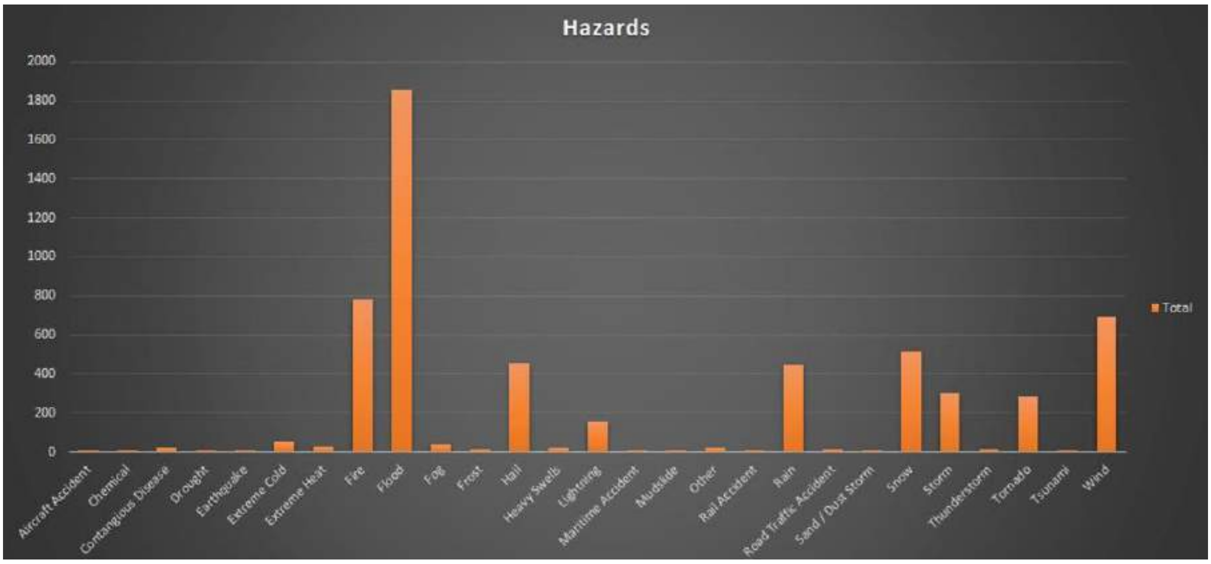


Figure 1.3: *Total events per hazard from the SRS (NDMC) and Caelum (SAWS) databases (1647-2013) (cited in Bruwer et al., 2017).*

A better perspective of the hail hazard may be obtained through studying insurance reports. It was reported by PwC that "*five insurers suffered losses of more than R170 million"* as a result of a storm on 27 November 2013 (PwC, 2014, p.19). This hailstorm was also reported to have exceeded R1.6 billion in short term insurance claims and described as "o*ne of the most catastrophic events experienced in South Africa to date*" (PwC, 2014, p.19; Havenga *et al.*, 2016).

The agricultural sector is another stakeholder that suffers heavy losses due to hailstorms. It is crucial that farmers know when the "hail season" might be expected, thus making hailstorm frequency studies and forecasts important. The South African GDP for agriculture for the 2017/2018 year attributed some of its losses to hail, especially in the Mpumalanga Province (Kuschke and Cassim, 2019). Piketh and Burger (2014) generated a recent hail frequency map, which shows hail hotspots in South Africa (see Figure 1.4). This should be helpful in areas such as Misgund in the Eastern Cape, which suffered from hailstorm events in 1985, 1987, 1992 and 1996, amounting to millions of Rands in damages. This is important in the context of knowing the predominant hazards that might affect farming, for emergency preparedness planning and the kind of insurance to obtain. Cases like these highlight that an area can have at least one severe hailstorm a year, which can be devastating. Not only does hail affect agriculture in South Africa, but the hazard has also made its mark on the Forestry industry (DEA, 2013).

Forested land in South Africa covers over 40 million hectares, of which 1.3 million hectares was planted in 2012 (FAO, 2015). Commercial forest products contributed R31.1 billion to the GDP in 2017, thus damage to the actual plantations may adversely impact such financial figures (Robertson, 2018). During hail events, trees experience physiological stress, which leaves them vulnerable to diseases such as *Diplodia pinea* and *Ceratocystis albifundus* (FAO, 2007; Bihon *et al.,* 2011).

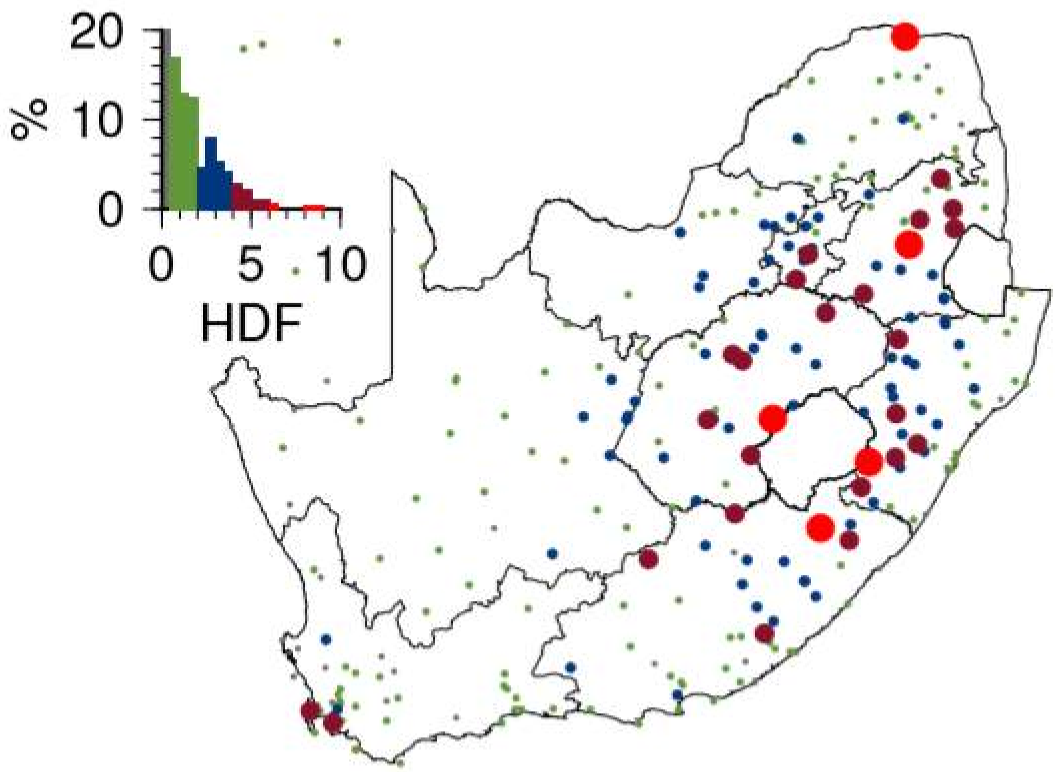


Figure 1.4: *Hail-day frequency map of South Africa created from Bureau (1986) and Caelum (1991) data and reports which is a compilation of SAWS observers reports of hail (Piketh and Burger, 2014; Havenga, 2018).*

The study of natural disasters from archives is of importance as it helps with projecting future risk and finding ways to manage a disaster (Pfister *et al.,* 2002). While hail is a very common phenomena to South Africa, associated mainly with summer rainstorms, there has been no previous attempt to examine the repercussions of hailstorms through the last century or more, and how such consequences may have changed through time.

This research is motivated by the absence of any such previous historical work for the southern African region. It is also motivated by the fact that hail/hailstorms threaten food and economic security by affecting sectors such as commercial and subsistence agriculture, and insurance (Prein and Holland, 2018). Although hailstorms may be catastrophic at times, these are difficult to predict or forecast in advance. A study such as the one presented in this dissertation, will hopefully provide new information on the temporal and spatial occurrence of destructive hailstorms in South Africa, and establish how society has responded to such events in the past.

1.4 AIMS AND OBJECTIVES

The aim of the research project is to establish the geographic and historic occurrence (temporally and spatially) of destructive hail events and hailstorms in South Africa. In addition, the study aims to determine the nature of consequences and human responses to such events in the last 119 years.

Research objectives are to:

- Determine and map the areal coverage of destructive hail/hailstorms in South Africa since 1900, as reported in based on newspaper articles.
- Determine the temporal patterns of destructive hail/hailstorms in South Africa since 1900.
- Identify any potential changes in the nature (severity, frequency) of destructive hailstorms over the last 119 years.
- Associate the characteristics of destructive hail/hailstorms with their consequences, including their impacts and responses.
- Interrogate the narrative framework that journalists use in newspapers when reporting on hail/hailstorm events.

1.5 THESIS OUTLINE

The dissertation includes five major chapters:

Chapter 1 first discusses the impacts of hail and then presents an overview on the literature of hailstorms and techniques used to study it. The chapter further discusses the role of media in reporting natural disasters. Lastly the motivation for the study and its aims and objectives are laid out.

Chapter 2 describes the study region and its climate followed by outlining the data and methodology. The data are described in detail and there is discussion of its use in such work. The methodology is outlined, including its limitations based on the nature of the data.

Chapter 3 presents the results and discussion of the geographic occurrence of destructive hail/ hailstorms. First, the statistics are detailed and compared to other studies, which is followed by outlining the areal distribution of such hail events.

Chapter 4 discusses the consequences of hail/hailstorms and associated human responses.

Chapter 5 is the final chapter and provides a summary of the results and discussions. The chapter also reflects on how the study aims and objectives were met.

2. DATA AND METHODOLOGY

2.1 STUDY REGION AND CLIMATE

The research is confined within the South African borders but excludes the landlocked Kingdom of Lesotho within South Africa. South Africa is located in the southern part of Africa, approximately 22°-35°S (Molekwa, 2013). Its northern boundaries are shared with Namibia, Botswana, Zimbabwe, Swaziland, and landlocks Lesotho. The Atlantic Ocean adjoins the South African west coast, while the Indian Ocean adjoins the east coast. The country has nine provinces (seen in Figure 2.1), namely Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, North West, Northern Cape, and Western Cape (Alexander, 2018).

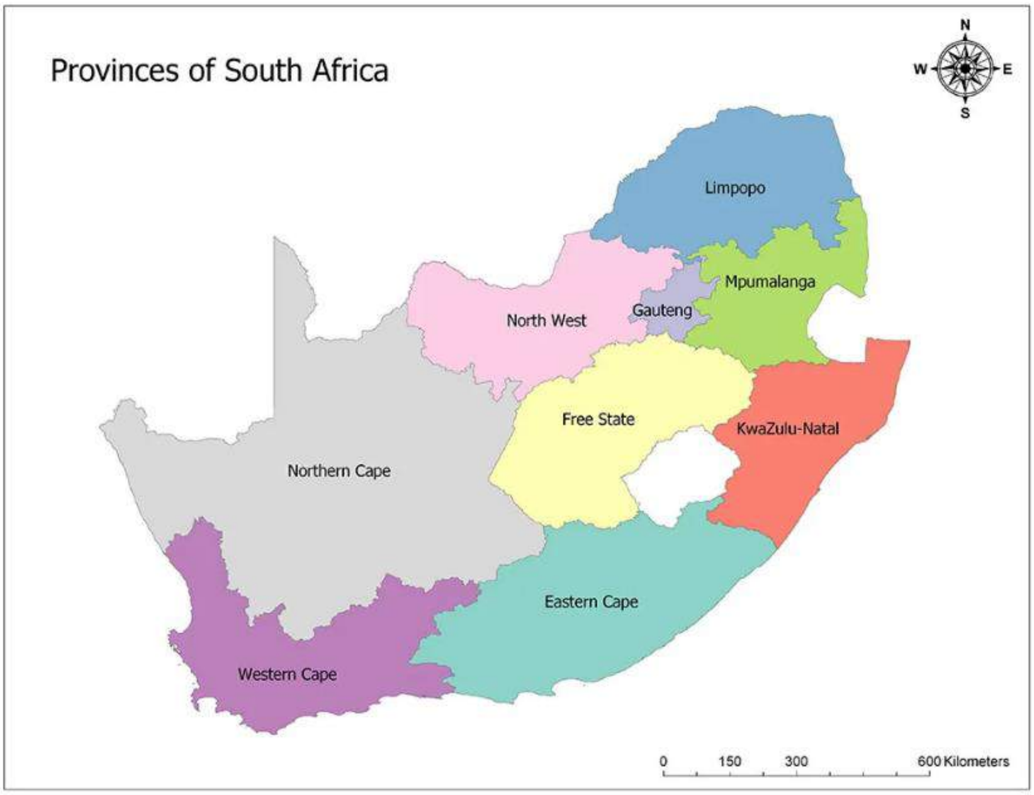


Figure 2.1: *Map of South Africa, study region, showing the locations of all nine provinces (Alexander, 2018)*

The South African climate is complex. Every climate system is comprised of multiple components that interact with each other at different scales, all depending on what the initial disturbance is (Trenberth *et al.,* 2000; Schneider *et al.*, 2003). The oceans surrounding the country have a major influence on its climate and how its weather systems operate. The El Niño-Southern Oscillation (ENSO) is responsible for many remote processes that drive annual and decadal climate variability including the tropical lows and mid-latitude cyclone processes that impact the country's climate (Hart *et al.,* 2010; Crétat *et al.,* 2012; Howard *et al.,* 2019).

2.1.1 Winter (June-August)

During winter, a subtropical high-pressure belt [namely the Continental High Pressure (CHP)] moves southwards, being well-established over South Africa (Tyson and Preston-Whyte, 2004, Wright *et al*.,2019). This prevents moisture from the South Atlantic High Pressure (SAHP) to the west and the South Indian High Pressure (SIHP) to the east from reaching the central plateau, thus creating stable conditions and lower winter rainfall in the interior of the country (Palmer and Ainslie, 2005; Chartan *et al*., 2018). Frontal systems are affected by the location and intensity of the mid-latitude storm tracks in the South Atlantic and Indian Oceans (Begley, 2005). Winter rainfall predominantly result from temperate frontal systems embedded in the westerlies that are enhanced by orographic and coastal influences, and other westerly disturbances such as cut-off lows (COLs) (Daron *et al*., 2019). The Southern Annular Mode (SAM) and winter rainfall are also interlinked (Reason and Rouault, 2005). The SAM measures the poleward extent of the circumpolar westerlies around the Antarctic continent which plays an important role in the geographical location of cold fronts (Reason and Rouault, 2005; Daron *et al*., 2019). Sea-surface temperatures (SSTs) and Antarctic sea-ice extent, together with anomalies in the winter subtropical jet, affect the meridional temperature gradient surface factors and regional circulation that likely influence rainfall and snowfall (Reason *et al*., 2002; Reason and Jagadheesha, 2005). The jet is strengthened just upstream of the south-Western Cape and significant cyclonic anomalies extend from the Southwestern Atlantic over the region (Reason *et* *al*., 2002). When cold fronts move northwards into the interior of the country, they result in cold waves that are responsible for the snowfall occurrence (Landman *et al*., 2017).

2.1.2 Spring (September -November)

During spring, enhanced solar radiation creates a heat low over the western parts of southern Africa (i.e., Northern Cape, Western Cape and parts of North West) (Landamn *et al*., 2017). Frontal systems sometimes result in COL pressure conditions that may cause extreme rainfall events during spring and autumn and snowfall over the interior (Preston-Whyte and Tyson 1988; Midgley and Lötze, 2008). Ridging high-pressure systems in the lower levels of the atmosphere, in combination with the westerly wind regime (westerly waves), are responsible for driving the spring rainfall peaks especially over the interior (Engelbrecht *et al*., 2015b; Landman *et al*., 2017). The moisture supply originating from the Indian Ocean is transported by easterly winds in the lower troposphere (Vigaud *et al*., 2009; Hart *et al*., 2010).

2.1.3 Summer (December – February)

Austral summer primarily takes place between the months October to March due to the southward migration of the tropical rainfall belt [inter-tropical convergence zone (ITCZ)]; allowing pulses of moisture from the tropics to frequently reach South Africa (Begley, 2005; Landman *et al*., 2017). The South Indian Ocean Dipole (SIOD), when positive, affects the likelihood of heavy rainfall events over eastern parts of southern Africa by bringing enhanced convergence of moisture – leading to the development of tropical temperature troughs (TTTs) (Behera *et al*., 2001; Reason, 2001; Fauchereau *et al*., 2003). El Niño (La Niña), associated with dry (wet) conditions, are linked with the displacement in the location of TTTs, are strongly linked to the austral summer rainfall and temperatures (Begley, 2005; Landman *et al*., 2017). TTTs develop when a tropical disturbance in the lower atmosphere is coupled with a mid-latitude trough in the upper atmosphere (Macron *et al*., 2014). The TTTs are also known to be the main rain-bearing system over subtropical southern Africa during austral summer and are responsible for 30-60% of rainfall occurring along the Cape south coast (where the all-year rainfall [AYR] occurs) during November, with the rest of the summer rainfall region (Singleton and Reason, 2007; Hart *et al*., 2013; Engelbrecht *et al*., 2015a). Sea-surface temperatures (SSTs) associated with the Indian Ocean are highly variable due to proximity with the Agulhas, Benguela and Antarctic circumpolar currents, with the Agulhas and Benguela currents controlling most rainfall during austral summer (Cook, 2000; Rouault *et al*., 2010; Muchuru *et al*., 2014, Jury, 2015).

During summer, heat-induced thunderstorms occur over the eastern escarpment and the Highveld areas (Landaman *et al.,* 2017). Supercells are highly organised severe thunderstorms with one intense updraft (usually rotating) and downdraft co-existing in a quasi-steady state rather than in the most usual state of an assemblage of convective cells, each of which has a relatively short lifespan, but which often produce severe weather including hail, lightning, strong winds and tornadoes (Pyle, 2006; Christodoulou and Sioutas, 2014). Hailstones are formed as frozen raindrops or graupel in cumulonimbus clouds (Heildorn, 2002). Updrafts and downdrafts are then responsible for the movement that increases the ice-layering of these raindrops or graupel (Courtier, 2020). Once the hailstones reach a weight heavy enough to overcome the updrafts, hailfall commences. Most hail either melts before reaching the ground or disintegrate within the interior of the thunderstorm (Heildorn, 2002)

2.1.4 Autumn (March-May)

The ITCZ advances northwards and subsidence dominates over the much of South Africa (Xulu *et al*., 2020). During this time, rainfall decreases rapidly over the eastern interior of the country (Landman *et al*., 2017). The all-year rainfall (AYR) region forms a boundary between the winter and summer rainfall region lying along the narrow strip along the Cape south coast between 21-27˚E (Engelbrecht *et al*., 2015b). This region receives rainfall from weather systems responsible for precipitation over the summer and winter rainfall regions, with rainfall peaks during autumn and spring (Engelbrecht *et al*., 2015b; Engelbrecht and Landman, 2016). Weather systems responsible for rainfall in the AYR region result from mid-latitude systems (cold fronts, west-wind troughs, COLs and ridging high pressure systems), tropical systems and convection from the north (TTTs), including the complex interactions and linkages between these very different systems (Muofhe *et al.*, 2020).

2.2 DATA

The main purpose for this study is to identify and analyse the various geographic attributes of hail/hailstorms over South Africa. Impact data are difficult to come by for many catastrophes in South Africa, which has led to researchers publishing in scientific journals and books on newspaper articles for such information (Grobler, 2003). This Masters study is conducted using newspaper articles on severe hail occurrences; these were obtained from the South African Weather Services library and from online newspaper archives.

The South African Weather Services has collections of newspaper articles of different weather-related natural disasters that have occurred in South Africa since earlier decades of the 20th century. Only newspapers referring to hail were obtained from this collection; these articles were then photographed for later use. Most of the newspapers were obtained from the online archive '*Readex*'. This entailed a general search starting with the word "*hail*", which was too broad for the search, as hail has an ambiguous meaning (for example, hail would be used in newspaper articles addressing the monarchy); and would include more newspaper reports. Another factor that had to be considered was the date of the article, which had to be no earlier than the year 1900. The list of publications in Table 2.1 are those of newspapers used for this research, with the number of newspapers and publications used (divided into 20-year intervals) is shown in Figure 2.2.

Table 2.1: *List of publications used for the research.*

Publications		
• Argus	• East Griqualand Fever	• Natal Witness
• Beeld	• Financial Mail	• Our Times
• Bloem Nuus	• Evening Post	• Parys Gazette
• Bolander	• Express Northern Cape	• Polokwane Observer
• Burger	• Finances and Tegniek	• Pretoria News
• Business Day	• Grocott's Mail	• Post
• Cape Argus	• Independent on Saturday	• Potchefstroom The Herald
• Cape Community	• Independent on Saturday (Durban)	• Rand Daily Mail
• Cape Times	• Isolomzi Fever (Port Shepstone)	• Rapport
• Carletonville Herald	• Kokstad Advertiser	• Rustenburg The Herald
• City Press	• Mafikeng Mail and Protectorate Guardian	• Saturday Star
• Daily Dispatch	• Mercury	• South Coast Fever
• Daily Sun	• Mercury (Durban)	• Sowetan
• Daily Mail	• Mercury Reporter	• Sunday independent
• Daily News	• Mthatha Express	• Sunday Sun
• Diamond Fever Advertiser	• Natal Mercury	• Sunday Times
• Diamond Field Advertiser	• The Journal	• The Cape Times
• Die Burger	• The Journal, Grahamstown	• Talk of the Town
• Die Volksbald	• TimesLIVE/ SowetanLIVE	• The Citizen
• Die Vaderland		• The Friend
• Die Volkstem		
• District Mail		
• E.P Herald		

• The Herald	• Upper Coast Fever	• The Times
• The Transvaal Leader	• Vista (Welkom)	• The Witness
• Transvaal	• Weekend Post	• Transvaal
• The Rep	• Weekend Argus	• Uzo Lwethu Fever
• UD Express	• Wits Vuvuzela	• Vrystaat
	• The Star	• The Natal News
	• The New Age	• The Mirror
	• Vaderland	• Hermanus Times

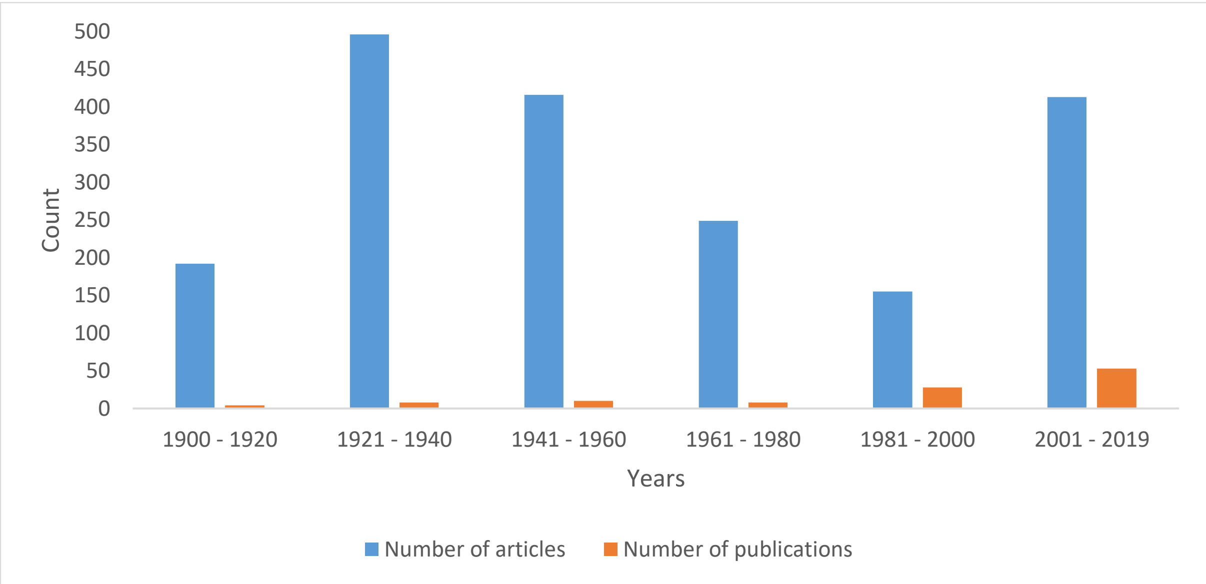


Figure 2.2: *Distribution of newspaper articles and publications over 20-year intervals.*

Each article was then analysed, based on the headings listed in Table 2.2, which was achieved through using Microsoft Excel. It is important to state that it is unlikely that all available newspaper articles covering South Africa were indeed collected given the vastness of newspapers and coverage over more than a century. In addition, not all articles contained all the information required to address each item of information looked for (i.e., heading). The date refers to the actual date that events took place, while the newspaper's date is under the '*Extra comments'* column.

Table 2.2: *Column headings for extracted newspaper data*.

Date	Time	Size of hailstones	Severity	Consequences	Human Response	Financial costs	Duration (of hail on the ground)	Area/s affected	Headline or not	Extra comments

Time refers to when the storm occurred. The reporting of this varied with each article, some would have the exact or approximate time, whilst some were reported as "*late afternoon*", "*around noon*" and "*evening*". When some events were reported more than once, the time would become more exact. For example, "*late afternoon*" would later be reported as "*4.15pm*" in a later article. Other hail events that may not have had the time or date reported, might have been revealed in an article even more than 3 months later.

The most commonly used hail severity scales are descriptive in nature, based on reported hail size/diameter of hailstones. The severity of the storm, in this research, refers to the wording used to describe the storm. Many of these would be featured in the article headline to highlight the event. For example, "*phenomenal storm*", "*severe*" and "*worst hail in 23 years*". The duration on the ground would also be reported in some articles and can be used to supplement the severity of hail. The location of reporting in the newspaper article itself, either has a headline or in a small column, may further be used to highlight the importance of the storm.

Human response refers to what was done in response to a hailstorm event or what was engaged with for hail hazard prevention. Some of the articles featured in newspapers about hail, were not about a hailstorm event as such, but rather about hail itself, to inform readers about its characteristics and mechanisms, such as-for example, hail formation. Other articles would be on topics about hail suppression and how it works, including the reactions farmers have about it. These types of articles are not featured in the table, but the contents were rather noted for presentation as discussion points in Chapter 4, where deemed relevant.

Financial costs contain the cost of damages, should the articles provide such information. Most of the cost of damages were estimates and not specific. Even where specific values were indicated, the cost would either differ or increase as the story develops. This is acceptably so because naturally the cost of a "*disaster*" would increase as the damage is assessed over time. This information would mainly accompany the information that would fall under the heading: '*consequences'*. Most of this information is from interviews undertaken with people who were affected by the storm. Some people would detail what they were doing during the storm, what the sky looked like, which animals were killed, the number of animals that had died, damage to property and loss of crops, amongst other things. Some newspaper articles would detail the weather associated with the hailstorm, such as windspeeds and the occurrence of lightning; such information is then detailed in the '*extra comments'* column.

One of the most important characteristics for hail is hailstone size, which usually determines the extent of the damage done by the hailstorm (Palencia *et al.,* 2010; Ni, 2017). The speed of the hailfall can also be determined by the size of the hailstone (Hohl *et al.,* 2002). In earlier hail research, the hailstone sizes would be described according to sizes of poultry eggs, fruit, and other circular objects (Touvinen *et al.,* 2018). The article would also describe the size of land that the hail affected. The location of the storm falls under the '*area/s affected*'. The heading has been made broad because hail does not necessarily fall within a constrained area only. From the articles, this is shown by more than one area being reported to having a hailstorm event and sometimes even at different times in a given day. Thus, a hail day, in this research, is defined as a single date in which a hailstorm event took place, irrespective of the number of reports that date has.

2.3 DATA CLASSIFICATION AND LAYOUT

Generally, newspaper articles are very rich with providing information on hail events. The real value is that such newspaper articles provide types of information associated with hail events that are not generally available from meteorological stations or satellite-based data (Laker *et al.*, 2012). From the wealth of information obtained from newspapers, the research achieves three sets of results. The newspaper articles were first chronologically sorted, starting with the earliest for each year. This was used to find other trends in hail events such as annual (to quantify number of extreme hail event days), seasonal and daily data (which includes for instance the time of day when such hail events took place). Hailstone size was first converted according to the sizes shown in Tables 2.3 and 2.4, before being used in any further contexts. The '*area/s affected'* data were then plotted onto the mapping tool Google Earth to demonstrate hail distribution. After working through all the newspaper articles collected, 1958 such articles or entries qualified for quantitative analyses (i.e., statistics and areal distribution presented in Chapter 3).

The socio-economic effects are presented with information obtained from '*consequences*', '*extra comments'*, '*severity'* and (hailstone) '*size*' data. Articles that did not include hail events were not included. These are statistically presented and used to produce a timeline of damage and progress of the nature of human response. Some of this information is presented through quotes.

Table 2.3: *Hailstone object to size intensity scale (after Bal et al., 2014).*

Size code	Typical hail diameter (mm)	Equivalent shape	Intensity category	Typical damage impacts
H0	< 8.4	Pea	Hard hail	No damage
H1	8.4 to 15.2	Marble	Potentially damaging	Slight damage to plants, crops
H2	15.2 to 20.3	Coin or grape	Potentially damaging	Significant damage to fruit, crops, vegetation
H3	20.3 to 30.5	Nickel to quarter	Severe	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored
H4	30.5 to 40.6	Golf ball	Severe	Widespread glass damage, vehicle bodywork damage
H5	40.6 to 50.8	Tennis ball	Destructive	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries
H6	50.8 to 61.0	Baseball	Destructive	Aircraft bodywork dented, brick walls pitted
H7	61.0 to 76.2	Grapefruit	Very destructive	Severe roof damage, risk of serious injuries
H8	76.2 to 88.9	Softball	Very destructive	Severe damage to aircraft bodywork
H9	88.9 to 101.6	Softball	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open
H10	>101.6	Softball and up	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open

Table 2.4: *Hailstone object-to size intensity scale with more variable objects (after State Climate Extreme Committee, 2009)*

HAIL SIZE (in.)	OBJECT ANALOG REPORTED
0.25	Pea
0.50	*Small marble**, moth ball
0.75	Penny, *large marble**
0.88	Nickel
1.00	Quarter
1.25	Half dollar
1.50	*Walnut**, Ping Pong ball
1.75	Golf ball
2.00	*Hen egg**, *Lime**
2.50	Tennis ball
2.75	Baseball
3.00	*Tea cup**, Hockey puck
4.00	12" Softball
4.50	*Grapefruit**
4.75	Computer CD or DVD

2.4 METHODOLOGICAL LIMITATIONS

As mentioned by others using documentary-based approaches to establish past weather, climate and hazards, a particular challenge is the subjective nature of source materials (Luterbacher *et al.,* 2000; De Kraker, 2006; Nash and Adamson, 2014). For example, descriptions of hail size and extent of damage might be exaggerated as there is a human tendency toward exaggerating negative events (Pinker, 2018). Some components of the results must hence be accepted as not necessarily providing a high precision of accuracy but rather accepted as '*relative*' or '*tentative*'. The temporal occurrence of some hail events also could not be determined with absolute precision (i.e., specific date) as some of the articles use words such as "*last week*" and "*over the weekend*", which makes it difficult to determine exactly when the hailstorm occurred, resulting in the gaps seen in the '*dates'* column (Appendix 1). The limitation begins when data from the chosen dates do not address required information for all the headings; typically, information about human response, duration of hail on the ground and the financial costs, are not regularly provided. A hail intensity index for hailstorms was difficult to achieve given widely variable reporting and subjectivity of reporting. However, the hailstone intensity index was possible and so may be a *relative* measure of storm intensity in terms of hail related hazard. This is presented and discussed in Chapter 3. The newspaper articles also vary in detail concerning the cost of damages incurred; with only 10% the articles mentioning any kind of cost, while many others were first reported as "*costs were still to be estimated"*, but then without an indication of costs involved in subsequent newspaper issues. Hence, information between articles is highly variable and inconsistent. Some place names (especially farm names) have changed over time and thus the exact locality of some hail events was either difficult to establish or could not be established at all. In such cases, the farm names would be individually searched, and location of the farm would be determined.

3. GEOGRAPHIC OCCURRENCE OF HAIL

3.1 TEMPORAL HAIL STATISTICS

3.1.1 Annual trends for hailstorms/hail

The reported occurrence of hail events (as collected through articles) over South Africa from 1900-2019, is shown in Figure 3.1. The high number of newspaper reports can also correspond to the damage caused to an extent, or the cost of damage. This is clearly highlighted in the year 2013, where there is double the number of reported cases compared to the actual hail days. It took more than one article or newspaper publication, in some cases, to obtain all the information needed for one hail event, which contributed to the trend seen in Figure 3.1. There are also instances where a hail event would only be reported years later, especially events in rural areas, due to the lack of service delivery, government response and insurance. Insurance is mentioned here as a high number of claims that can attract media attention, and subsequently make a given severe hail event "*known"*, which would have otherwise gone unnoticed beyond the community directly affected by it.

A hail day is defined as a day with a known occurrence of a severe hail occurrence, whereas a hail reporting refers to the number of newspaper articles reporting on a given hail event (also described in Chapter 2 – p.23). The total number of reported severe hail days over the period 1900-2019 is 1281, compared to the 1963 reports covering those events. This means that some severe hail days receive numerous reports across different newspapers. The Rand Daily Mail newspaper accounts for 65% of the articles covering the hail events. However, given that this newspaper publisher closed in 1985, this likely influences the reduced number of events recorded between 1985 and ~2005. The higher number of records since 2005 are likely owing to increased number of publications and thus articles reporting on severe hail events. The list of newspaper publishers is listed in Chapter 2 (p.20) and can also be contextualised in Appendix 1.

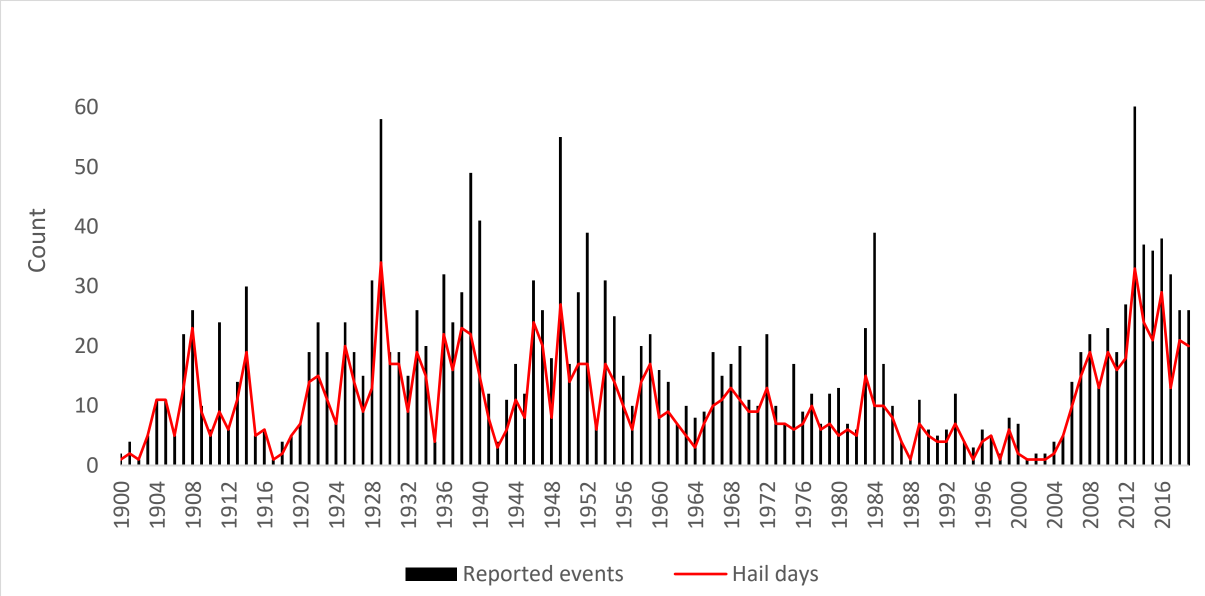


Figure 3.1: *Number of newspaper-reported hail (black bars) and hail cases/events (red solid line) per year between 1900-2019 (Appendix 1).*

In the process of extracting hail events from newspaper articles, descriptions of the accompanying weather were mentioned. These are detailed and graphed in Figure 3.2, but also provided in Appendix 1. These were subject to the extent of description provided by an author and detail of accounts provided by members of the public who were directly impacted by the given hail events or witnessed the event. The eyewitness accounts were of importance to determine at which time the hailfall took place (before, during or after the weather event), which would assist in weather development research when studying a particular weather-related event. 26% (510 articles) of all newspaper articles (1963 articles) were consulted to produce Figure 3.2. Of the 530 articles, 41% mentioned strong wind and gale-force winds, 14% mentioned lightning, 12% mentioned floods and 11.5% mentioned general rains and torrential rains. All other weather-related mentions each contributed less than 10%. The difference in the number of reports differs because hailstones caused blockages which caused some of the reported flooding.

3.1.1.1 Winds and hail

As mentioned earlier, one of the primary requirements for hail formation are updrafts and hence associated wind (Allen *et al.,* 2015). After the formation of a hailstone, strong wind shear is accountable for the strength of the hailstone's impact velocity, which is attributed to horizontal wind shear (Olivier, 1990; Li *et al.,* 2016*;* Dieling *et al.*, 2020). Wind (or wind descriptions) are the most referenced when hail is reported (Figure 3.2).

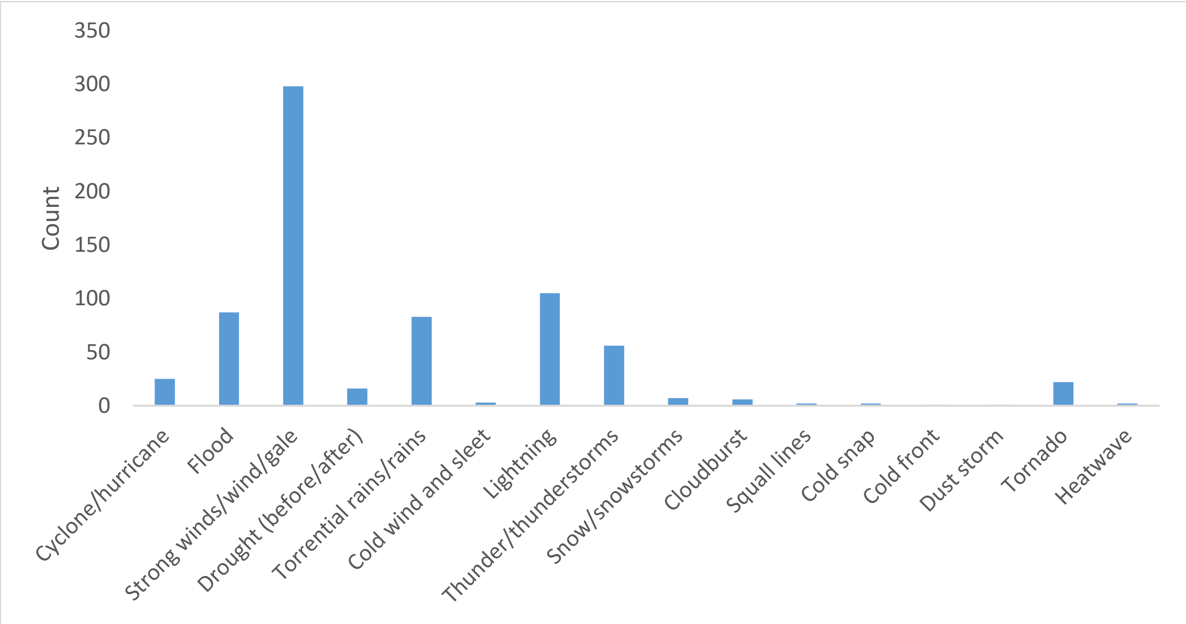


Figure 3.2: Weather related events that were reported to accompany hail/hailstorms over the period 1900-2019 (from 510 articles).

Wind (or wind descriptions) is mentioned 298 times, with only 6% of these mentions with wind speeds with defined values (presented in Appendix 2). Wind speeds reported ranged from 65km/h to 180km/h, with hailstone sizes ranging from '*eggs*' to '*tennis balls*'. Of the reported wind speeds (the 6%), only 31% is accompanied with hailstone size information. Another approach to determining the wind speed is through the descriptions used, such as cyclone, hurricane, and gale force winds. Cyclonic and hurricane winds (1% of 298 wind mentions) range from 89-221km/h, reported defined values ranged from 112.65-180km/h. The hailstone sizes ranged from 12.7-72.9mm in diameter. Gale force winds (24% of 298 wind mentions) range from 63-97km/h, reported defined values ranged from 65-128.74km/h. The hailstone sizes from 28-152mm in diameter. The ratio between reported wind speeds and hailstone sizes does not reach 50% (only reaching 31%), thus a strong correlation is not possible. As winds are always associated with hail events, the number of reports with mention of winds does not mean that wind was not present. This presents as a limitation as the detail of reporting can affect what is included and analysed in this research.

A better comparison of hailstone to wind speed is to examine the impact damage (discussed in Chapter 4). For example, "*Fortunately, owing to the absence of wind, the damage was mainly confined to fruit trees and greenhouses."* (Rand Daily Mail, 15 September 1905, page 8), "*The absence of wind during the storm practically saved the crops."* (Rand Daily Mail, 7 November 1911, page 10) and *"Driven at this speed the hail -small in size- cut like a knife."* (Rand Daily Mail, 6 November 1914). Newspaper articles that detailed when hailfall occurred with respect to wind is important, as this can cause difficulty in assigning storm damage featuring hail, as only hail-related damage. This could also cause a discrepancy for insurance claims, where all reports are reported as hail damage, when in fact wind or other factors of the storm were at least part of the cause. Hail research using primarily insurance claims as data should need to consider this. Wind direction is not, however, mentioned as often and thus not much can be gained from such descriptions.

Results from the newspaper reports (298 mentions) show that 7% of wind-hail reports is due to wind damage, 51% of wind-hail reports is due to hail damage, 14% of wind-hail reports is combined damage and 28% of wind-hail reports was unspecified (Figure 3.3). Combined damage refers to occurrences such as: "*As the strong winds began levelling trees and ripping the roofs off houses, hail came pounding down."* (Langa, 2016, page 6). There was some difficulty in determining when the hailfall took place, whether pre-, during or after the wind-hail event; newspaper articles reported hail accompanying the wind (12.6% of the 298 wind-hail reports) or wind accompanied by the hailfall (72.4% of the 298 wind-hail reports), this shows which event (hail or wind) was dominant (Appendix 1).

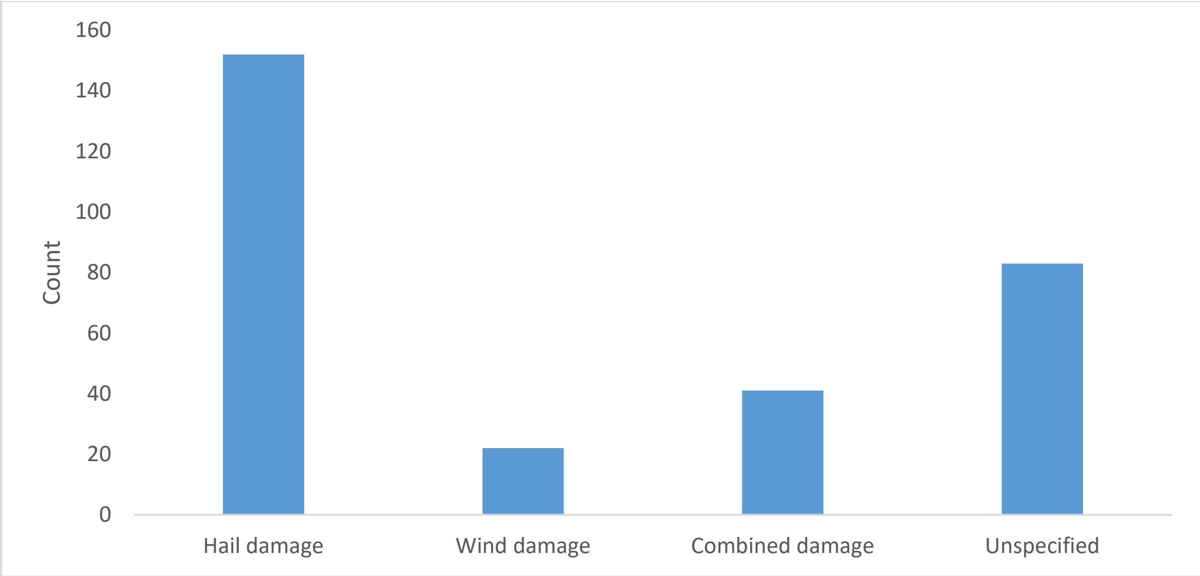


Figure 3.3: *A distinction of between wind-hail damage reported in newspaper reports from 1900-2019 (298 wind-hail references).*

3.1.1.2 Tornadoes and hail

The occurrence of hail with tornadoes is not uncommon, as they share the same wind conditions in a thunderstorm cell (Renaud,2022). Both a hailstorm and tornado may occur from one thunderstorm event where there is the formation a supercell storm (Groenemeijer and Van Delden, 2007). A supercell typically has broad and intense updrafts that bring moisture from the surface air into the storm (Stough *et al.,* 2021). The updraft rises and begins to rotate, with an anvil forming in the direction where the updraft exits (Cotton *et al.,* 2011). The updraft speeds have the ability to carry raindrops into areas below freezing within the cloud, suspending them there for enough interaction (wind shear) for the growth of hailstones (Cotton and Pielke Sr, 2007; Barrett and Hoose, 2022). When the environment (i.e., winds) is favourable, the updraft and downdraft of a storm become organised and twist around and reinforce each other (Cotton *et al.,* 2011; Markowski and Richardson, 2014). When moisture condenses and precipitation begins, including the fall of hailstones, the rotating updrafts persist - pulling warm air and moisture upward and pushing cold dry air toward the ground forming a tornado (Seargent, 2012; Markowski and Richardson, 2014). This could be the possible explanation for the results in Figure 3.4.

An example of this process is from the infamous "Lahoma Storm" of 17 August 1994 which occurred over Lahoma, USA. This was a multicellular hailstorm which produced a brief F1 tornado with winds reaching about 182km/h (Lemon *et al.*, 1996). This storm was also associated with golf-ball sized hailstones (McNutt, 1994). Tornadoes are frequently associated with severe hail (Baggett *et al.,* 2018; Converse, 2020; Wunsch and French, 2020), either preceding or occurring after the tornado.

Tornadoes are associated with 4% (21 mentions) of articles used for Figure 3.2. 57% of tornado-hail reports (of the 4%) mentioned hail to have occurred before the tornado (Figure 3.4): "…*when the sky suddenly went dark, hail and rain started falling and the wind picked up…*" (MacGregor, 2008); "*At about 5pm, the sun disappeared, blackness filled the sky and hail and rain pelted down. Minutes later, a tornado swept through the towns…*" (Pillay, 2012, page 6). 19% of tornado-hail reports of the 1%) mentioned hail to have occurred after the tornado, 19% of tornado-hail reports mentioned hail to have occurred during the tornado (for example, a tornado would affect one area while there is a hailfall) and 5% was unspecified (Figure 3.4). The damage reported as a result of the tornado-hail events was caused by hail (33%), wind (19%), combined (19%) and unspecified (29%). All these percentages are calculated against the 4% (21 mentions).

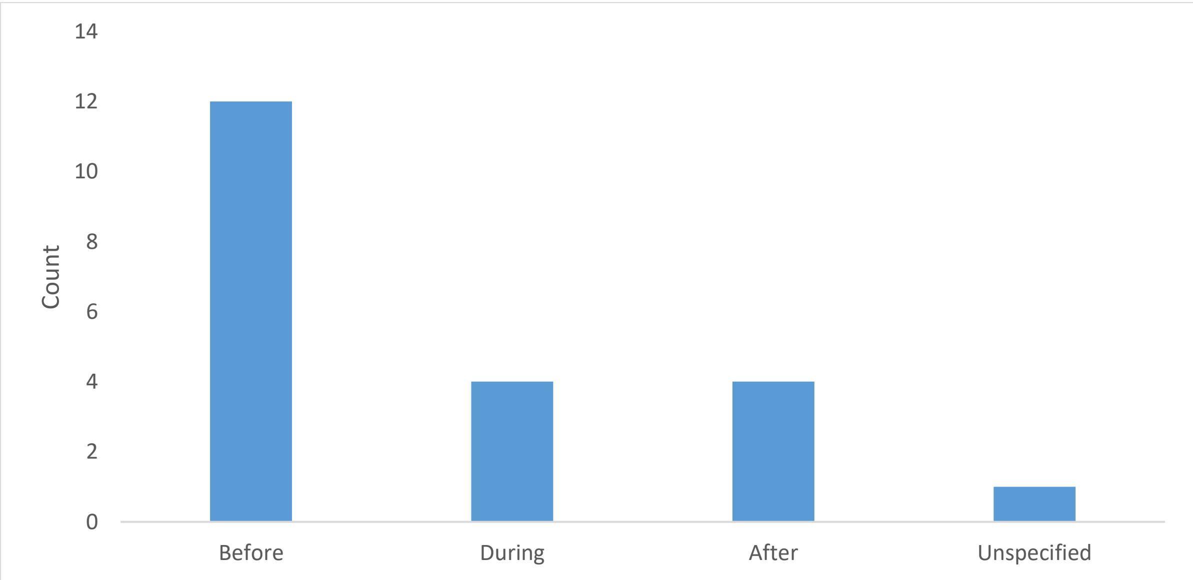


Figure 3.4: *Timing of hailfall when accompanying a tornado from hail-reporting newspaper articles from 1900-2019 (21 articles).*

3.1.1.3 Thunderstorms, lightning, and hail

Punge *et al.* (2021) concludes that thunderstorm data from space-borne observations can be used to derive hail hazards. Hailstorms are usually initiated within thunderstorm conditions (De Coning and Adam*.,* 2000; Bal *et al.,* 2014; Raupach *et al.,* 2021). Thunder/thunderstorms accounted for 11% of the newspaper articles used for Figure 3.2. This does not suggest thunderstorms occur only 11% of the time but rather based on the reporting of the word '*thunder/thunderstorm'*. Thus, the percentages presented below are calculated from this 8%.

Several authors have written about the common association between lightning and hail occurrence (e.g., Pakiam and Maybank, 1969; Emersic *et al.,* 2010; Dimitrova *et al.,* 2013; Bednarczyk and Sousounis, 2012; Akhmedovic, 2014, Santos and Belo-Perreira, 2019, Dowdy, 2020). Lightning was the second most mentioned with weather-related mentions with 105 mentions (20.5% of newspaper articles used in Figure 3.2. Lightning accompanying a hailstorm accounted for 76% of the 105 lightning-hail mentions and hailstorm accompanying lightning is accounted for by nine cases (8.57% of the 105 lightning mentions). Lightning can cause its own related damage and casualties, e.g., two oxen were killed by lightning during a hailstorm reported in the Rand Daily Mail (26 November 1908) and two cases related to human casualties: one case did not specify whether it was due to hail or lightning (Rand Daily Mail, 20 October 1938), whilst the other case reported one person being struck by lightning during a hailstorm (Mhlana, 2015).

3.1.1.4 Droughts and hail

An interesting climate condition mentioned was drought, where hail was described to have '*broken'* the drought; meaning it occurred after. Drought accounts for 3% of newspaper articles used to produce Figure 3.2. Of these occasions, 81% stated that hail took place after long periods of droughts, sometimes intensifying the damage to the farming industry:

"*Further details have been received here of damage done during the recent storms which marked the break-up of the long drought."* (Rand Daily Mail, 11 December 1911, page 7).

"*The drought was broken by a severe hailstorm at Heidelberg which passed over the town during the lunch hour."* (Rand Daily Mail, 6 November 1937, page 14).

Long-term forecaster Emsie Klopper explained these occasions using the 1997/98 El Niño, which was the worst at the time in the country, that it "*Causes the sea surface temperature to rise, usually brings good spring rains coupled with thunderstorms and hail, as currently the case. This is followed by below-normal summer rainfall and high temperatures from November to March."* (Business Day, 17 October 1997). This explanation is further explained by Professor Mary Scholes in stating (about the 2015/16 El Niño): "*We might get late summer rainfall after March. The severity of the storms, when we do get a rainfall event, might be a high-intensity hail event with low-intensity rain".* (Diamond Fields Advertiser, 5 January 2016, page 4). ENSO events have the ability to influence storm frequency and intensity (Liu *et al.,* 2018); Begley (2005) mentions that El Niño is associated with dry conditions, including an increase in temperatures and hailstorm events in South Africa. Karagioras and Kourtidis (2021) establish that there can be a difference in intensity between rain and hail in a single storm event through their study of how rain, snow, and hail impact atmospheric electric field near the ground. Their paper discovers that there was higher decrease in the potential gradient when a hail event occurs without rain (between -2500 and -7500 V/m) compared to the decrease in the potential gradient when a hail event occurs before or after rainfall (-2500 and -5000V/m). Thus, considering Professor Mary Scholes' statement, research on the impact the 2015/16 El Niño on the atmospheric electric field near ground would be worth investigating.

In southern Africa, the effects of ENSO phases are such that El Niño shortens the rainy season, and La Niña tends to lengthen it (Moeletsi *et al.,* 2011). ENSO phases directly affect convective activity, and thus the occurrence of hailstorms, and thus an analysis between ENSO phases and hail is relevant. According to Allen *et al*. (2015), the frequency of tornadoes and hail can be related to ENSO phases and concluded that frequencies of such events is higher during the La Niña phase than El Niño phase for the northern hemisphere (e.g., Rhome *et al.,* 2000; Lepore *et al.,* 2017). However, in the southern hemisphere, studies have shown quite the opposite. Hail day frequencies (same as in Figure 3.1) during the period 1900-2019 are studied in connection with (El Niño and La Niña) ENSO phases (Figure 3.5). Of the 119 years, 42.8% experienced an El Niño phase and 39.5% experienced a La Niña phase. With that noted, the years correlating with La Niña phases had a greater number of hail days than El Niño (Figure 3.5).

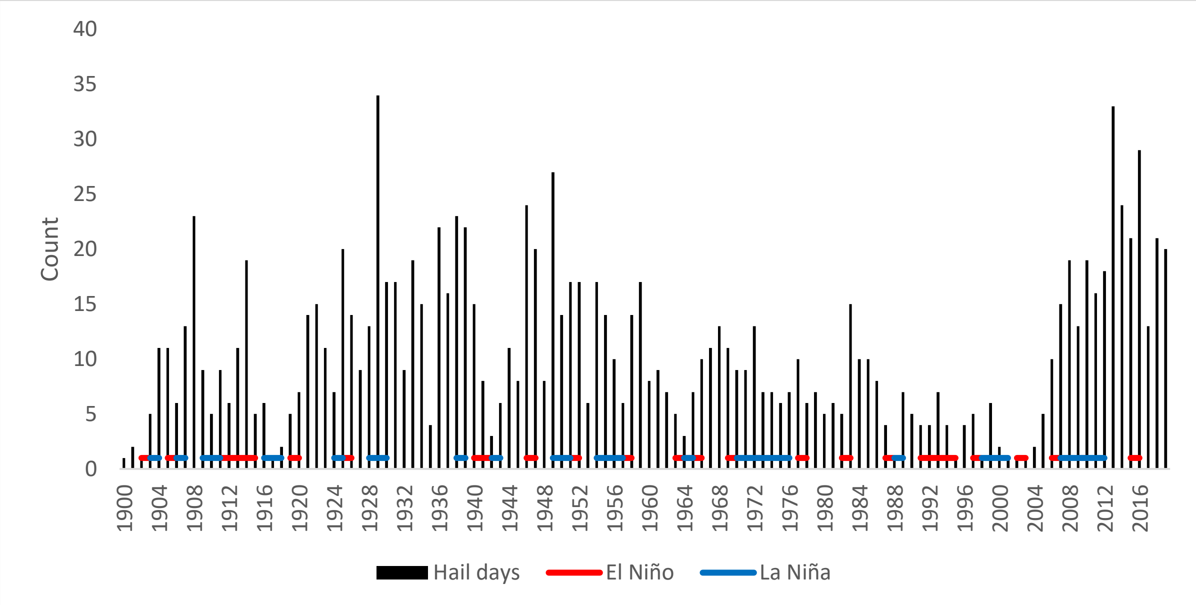


Figure 3.5: *Number of hail days (black bars) compared with warm (El Niño - red horizontal lines) and cold (La Niña - blue horizontal lines) ENSO phases from 1900-2019 (data calculated from Appendix 1).*

Bruick (2019) studied this relationship in sub-tropical South America and found that storms during the El Niño phase tended to be deeper and contain stronger convection, thus more strongly connected with hailstorms. Soderholm *et al*. (2017) have also reported a strong relationship between El Niño and damaging hailstorms. However, Soderholm *et al.* (2017) elaborates that while hailstorms are infrequent during droughts, they tend to occur immediately after, and hence during the terminal phases of El Niño. Although the hail days in these studies depend on the reported events, for example, during the 1997/98 El Niño influenced drought, there were greater number of articles reporting on the drought than any other weather-related disasters.

3.1.2 Seasonal trends for hailstorms/hail

Figure 3.6 shows which months had the most hailstorm events; November has the highest hailstorm cases reported with an overall 453 (23%) out of the 1963 newspaper reports. This compares favourably with studies of more climatological focus studying hailfall frequency, which have likewise found that hail frequency peaks in the month of November (Olivier,1990; Havenga, 2018; Simpson and Dyson, 2018). This also places some level of confidence in the documentary-based (i.e., newspapers) approach used in this dissertation. 70% (of the 1963 newspaper reports) of hailstorm activity takes place between the months October and January, which fall under South Africa's austral summer (October to March) (Blamely *et al.,* 2017).

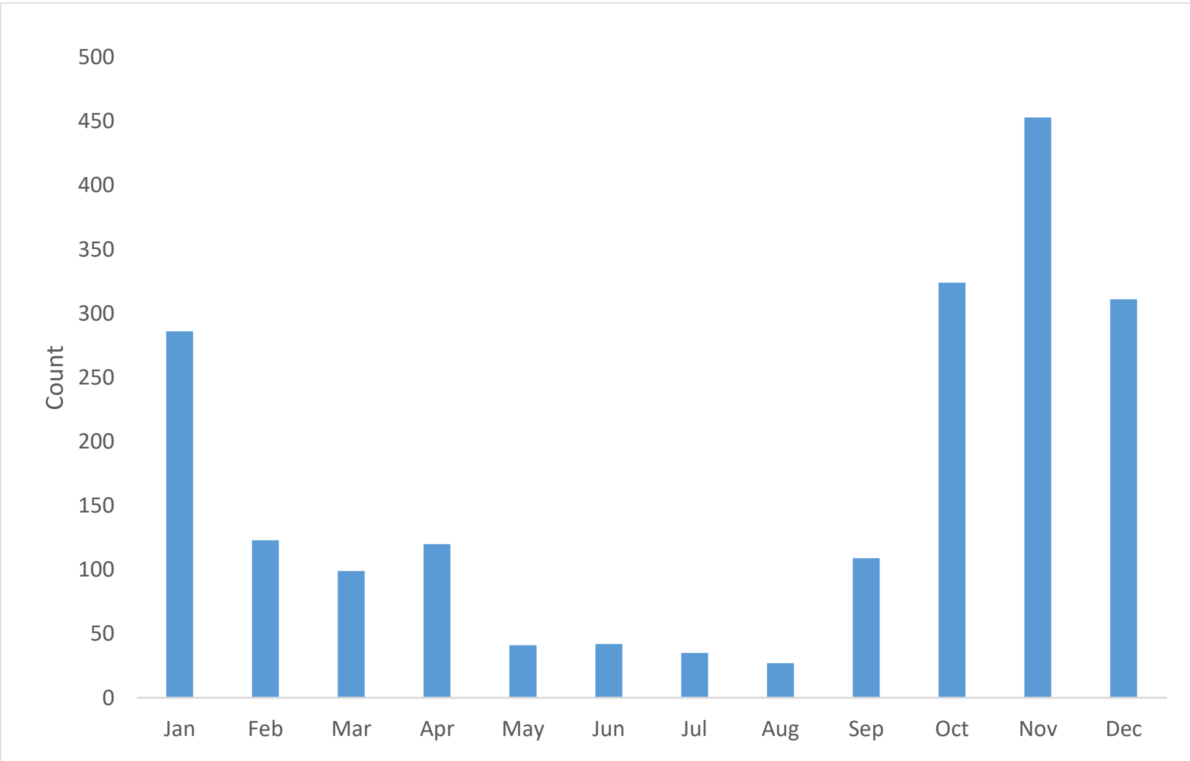


Figure 3.6: *Number of times a hail event was reported by newspapers for each month from 1900 to 2019.*

Figure 3.7 also reinforces this trend, which shows a chronological development of convective storms which are well-developed in November/December and begin to show movement and disintegration well before the winter months. The results presented in Appendix 3, where the hailstorms show an increase during the transition between austral summer and winter (+1% from March to April) and an increase from austral winter to summer (+4.5% from August to September); percentages calculated against overall number of newspaper reports. This can be explained by a drop in pressure that is frequently associated with large-scale upward motion and moisture influx convergence (inter-seasonal movement of the ITCZ), correlating to the frontal synoptic features that produce a drop in pressure in the leeward side of the Cape Mountains when the frontal systems are slowed down (Palencia *et al.,* 2009). This means hail occurrence gradually decreases towards the winter months – which can be explained by the ITCZ moving northwards and subsidence setting over the larger parts of the country, reducing the amount of convection required for thunderstorm (hail) formation (Landman *et al.,* 2017).

Hail occurrence also transitions from the eastern parts of the country to the west – following the seasonal trend of cold fronts bringing rain over the winter rainfall region (WRR) whilst the eastern parts of the country is dominated by a subtropical high-pressure belt which results in sparse rainfall (Du Plessis and Schloms, 2017; Daron *et al.,* 2019).

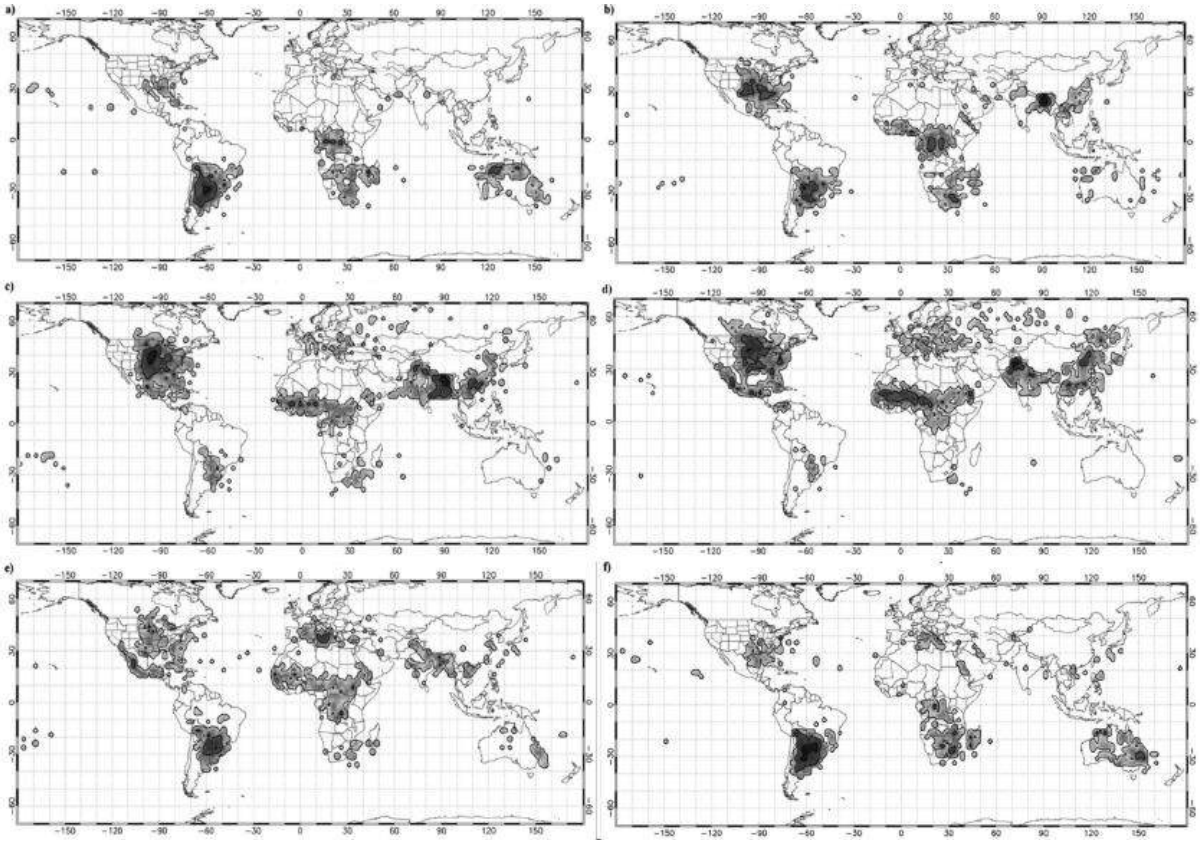


Figure 3.7: *Hail climatology bi-monthly frequency based on ARMS-E observations from 2003 to 2010 (adapted by Havenga (2018) after Cecil and Blankenship (2012)). The figures are ordered as follows: a) January/February, b) March/April, c) May/June, d) July/August, e) September/October, f) November/December.*

Appendix 3 demonstrates the monthly hail events and hail days for each province from 1900 to 2019. To demonstrate this transition, the hail days exhibit the following monthly trends from the overall newspaper reports: Gauteng province has the highest number of reported hail events and hail days (665 days and 411 days respectively), followed by KZN (334 days and 311 days respectively). Most provinces, apart from KZN and the Eastern Cape record their highest hail frequency in the month of November (Appendix 3). Seven provinces experience hail frequency peaks in November, the percentage annual hail occurrence for November for each province is as follows: Limpopo (39.7%), Gauteng (25%), Mpumalanga (20.1%), North West (24.5%), Free State (22%), Northern Cape (26%) and Western Cape (16.4%). The Eastern Cape hail frequency peaks in January

(21.8%), whilst in KZN hail frequency peak month is December (19%) (Appendix 3). The established monthly trends presented, are challenged by the latest research by Punge *et al*. (2021), whose work (Figure 3.8), shows the month January as having the highest number of hail events, followed by December. Figure 3.8 presents this data using Julian days of the year, and this goes for most of the figures presented in Punge *et al*. (2021). Punge *et al*. (2021) bases these results from the use of 14 years (2005-2018) of geostationary satellite observations of convective storms, overlapping parts of this research. The monthly peak difference between Punge *et al.* (2021) and this research stems from the type of data used, convective storm frequency does not directly translate to hail events and the use of satellite imagery does tend to overestimate hail occurrence.

The western provinces, Northern Cape, and Western Cape, show notable winter peaks. The Northern Cape winter peak is in July (2%), whilst the Western Cape peaks in June (9.6%) (percentages calculated according to the total hail days of each month per province, shown in Appendix 3). The winter peak in the Western Cape is not distinct, due to the fairly even distribution of hail events throughout the year (Appendix 3). The Western Cape rainfall is a result of atmospheric rivers and COLs in the summer and cold fronts that result in winter rainfall; COLs and cold fronts have been mentioned to occur with hail (Figure 3.2) (De Kock *et al.,*2021). The provinces that exhibit a notable increase in hail days in the month of April from March are Mpumalanga (+2 hail days), North West (+5 hail days), KZN (+4 hail days), Free State (+5 hail days) and the Northern Cape (+4 hail days) (Appendix 3) and may attribute to the peak seen in Figure 3.6.

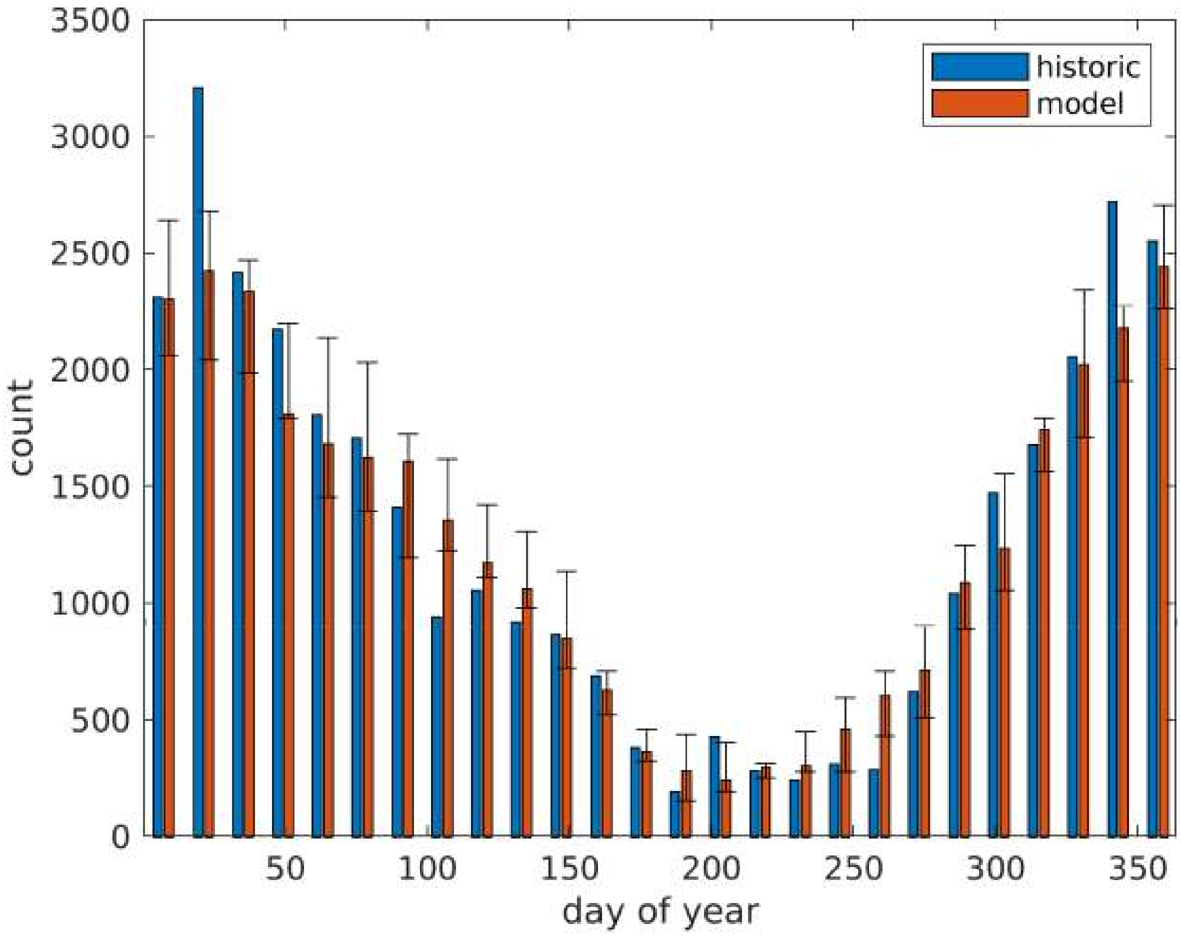


Figure 3.8: *Daily distribution of hail events based on historic and stochastic model events (Punge et al., 2021).*

Weather related events associated with hailfall were investigated to find reasoning to the increase in hail days seen in April (Figure 3.6 and Figure 3.9). Figure 3.9 shows an overall increase in strong winds, torrential rains, thunderstorms, and lightning of +1%, +5%, +5% and +2% respectively in occurrence from the month of March to April (percentages calculated according to the total frequency of mentions for each month); these are important ingredients for the development of hailstorms and an increase in these conditions increases the probability of hailstorms in the month of April. The reasons for this increase will not be explored in this study. The same trend is seen in the month of September, which marks the beginning of austral summer, when the increase in severe hail events is anticipated. The occurrence of cyclonic winds, floods, strong winds, torrential rains lightning, thunderstorms events increase in the month of September. This corresponds with findings in Kruger and Mbatha (2021), reporting that the first spring rains, which can be include significant thunderstorm activity, are often accompanied by strong winds and hail. Thunderstorm activity increases due to the influx of moisture from location of the ITCZ in spring, increasing convective action due to the surface heating (Landman *et al.,* 2017). The monthly occurrence of the weather types and conditions are shown in Appendix 4.

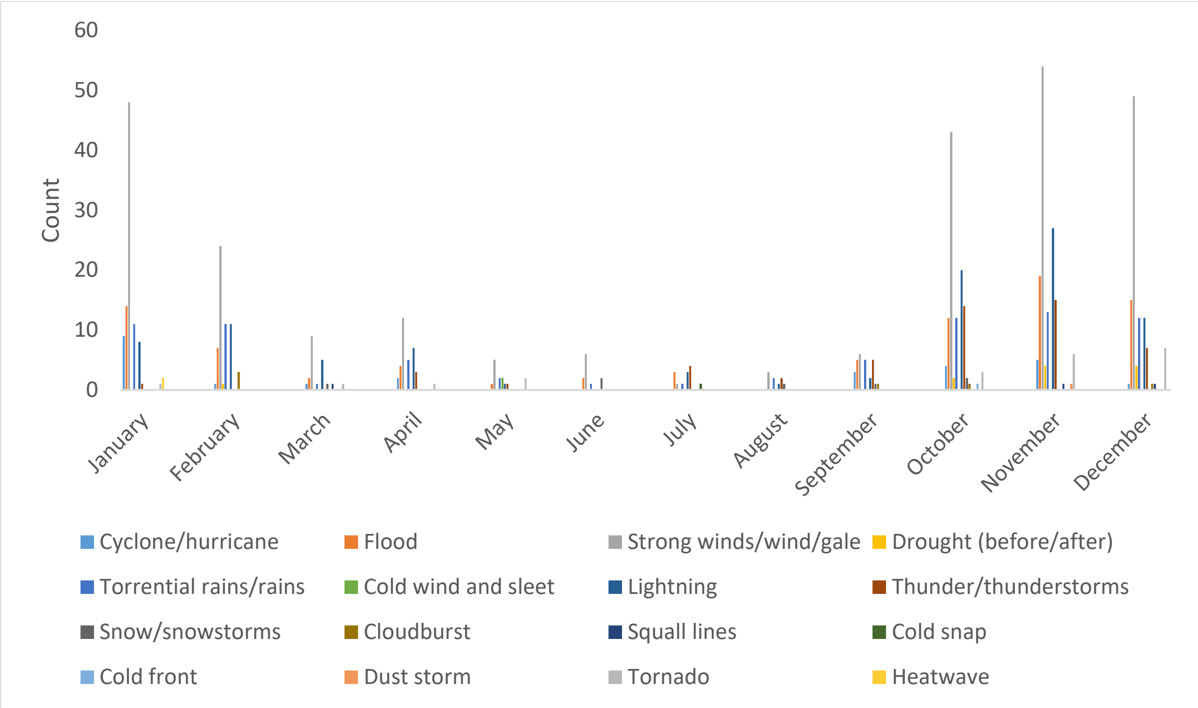


Figure 3.9: *Weather related events that there reported to accompany hail/hailstorm in newspapers from 1900-2019, presented by monthly occurrence.*

The monthly percentage distribution of hail events over 20-year intervals is presented in Figure 3.10. The number of reported hail events varies widely due to the number of newspaper articles and publications used during each interval (Figure 2.2). The number of publications steadily increases with each interval; however, the number of articles vary. The interval with the most articles is 1921-1940 (25% of all newspaper articles), followed by 1941-1960 (21.2% of all newspaper articles) and 2001-2019 (21% of all newspaper articles). All but the 1961-1980 interval reports November as the month with the highest severe hail events, with December reported as the month with the highest severe hail events. Figure 3.10 also shows that severe hail events occur in all months of the year, with the exception that there are no reported severe hail events in the month of June in the 1900-1920 interval.

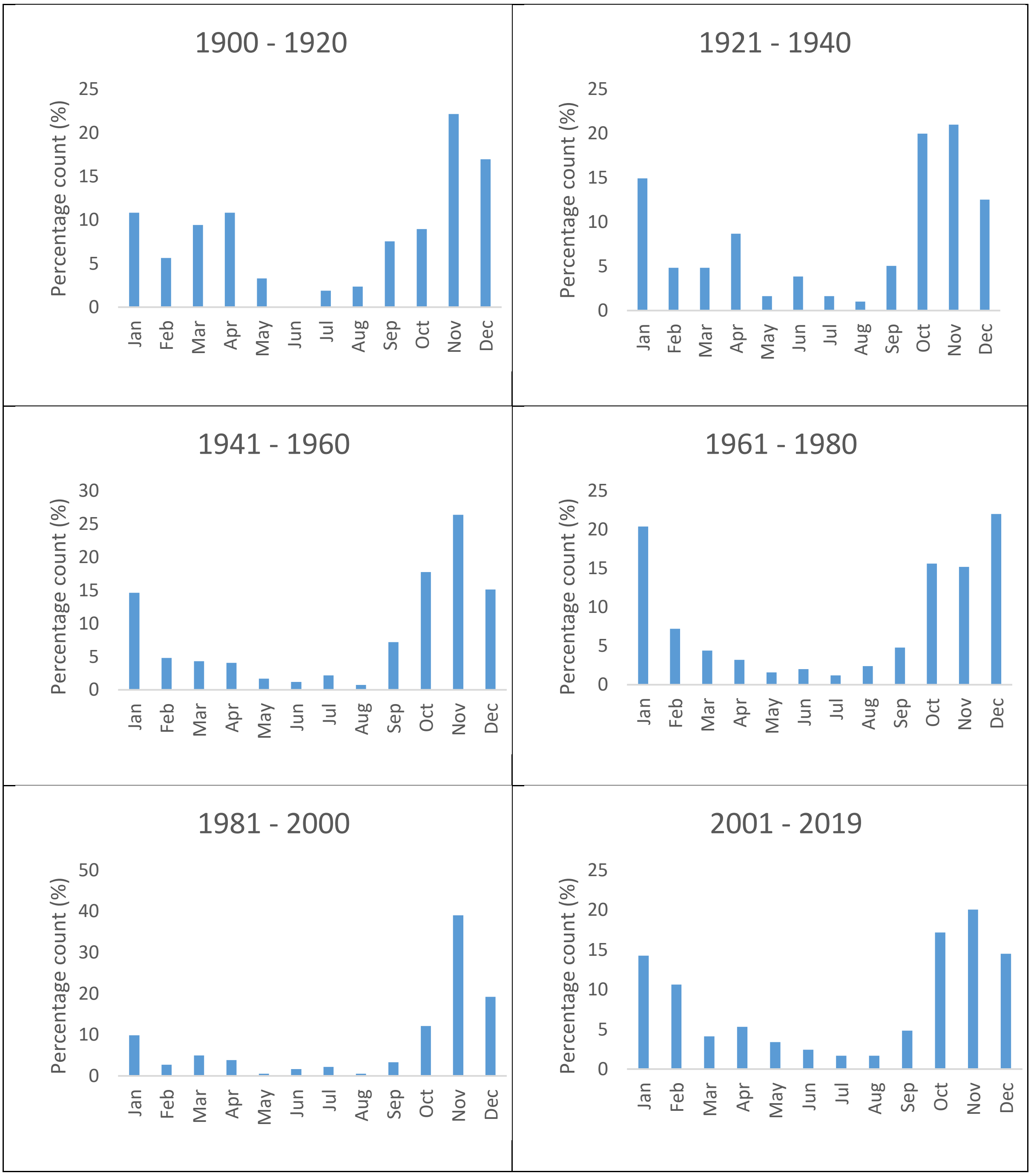


Figure 3.10: *Total monthly frequency distribution of newspaper reported hail events over 20-year intervals.*

3.1.3 Diurnal trends of hailstorms/hail

Figure 3.11 demonstrates four bins that were chosen: 06:00 - 12:00 (morning), 14:00-18:00 (afternoon), 18:00 - 00:00 (evening/night) and 00:00-06:00 (early morning), these were chosen to include as many datasets as possible. The times in the newspapers either reported the exact time of occurrence or reported time in respect to morning, afternoon etc. The afternoon times were divided into two, to examine the accuracy of the fact that hail takes place in the late afternoon and due to the varying terms used to describe the times (De *Coning and Adam,* 2015; Pienaar *et al.,* 2015). Early afternoon and late afternoon were divided with the time 12:00-15:00 or lunch/early afternoon and 15:00-18:00 or late afternoon, respectively (see Figure 3.12). From the newspaper articles used, 1048 (53% of all newspaper reports) mentioned what time of day the hail events occurred, however, only 251 (12.8% of all newspaper reports) stated the digital time.

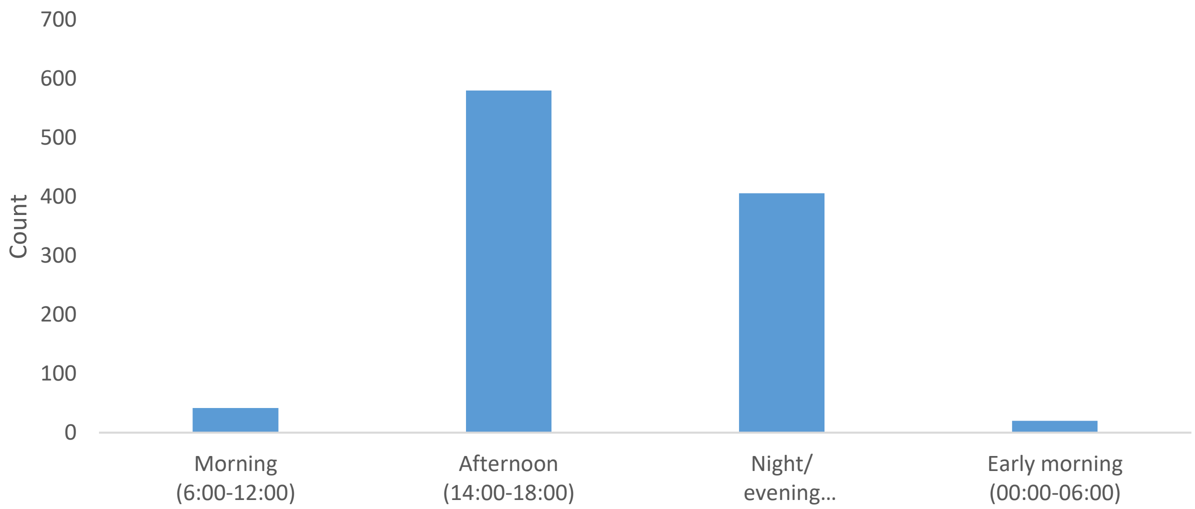


Figure 3.11: *The temporal distribution of newspaper reported hail events from 1900-2019.*

Most (55% of the 1048 newspaper articles used to produce Figure 3.11) hail events occurred during the afternoon between 14:00 and 18:00 (Figure 3.11), between 15:00 and 18:00 (Figure 3.12). Evening and night hailstorms account for 39% of the 1048 newspaper articles, of these, the digital time given showed 6.4% occurring before 19:00 and 16.5% occur between 19:00 and 00:00

(percentages calculated against 1048 newspaper articles). The latest given digital time given for night time was 22:55, with 0.5% (of all 508 night time reports) reported to occur at midnight. The occurrence of evening/night time hail events can be attributed to the overlap from the late afternoon convection activity (Olivier, 1990). The overlap in convection activity can be attributed to air near the ground not cooling as rapidly as it does in the atmosphere (Olivier, 1990; Thiery *et al.,* 2016). This makes it possible for thunderstorms to occur during the night, as seen in the results. The air near the ground does not cool as rapidly because it contains more moisture than the air above the ground, making it possible for convection to continue well into the night (Thiery *et al.,* 2016). There is also an overlap in the times between afternoon and evening, with evening staring from 17:00 to 19:00. When hail is described as occurring in the evening, it is not clear whether if occurred before 18:00, which is the latest time described for the afternoon in the study. This may partially explain the high number of hail events in the evening.

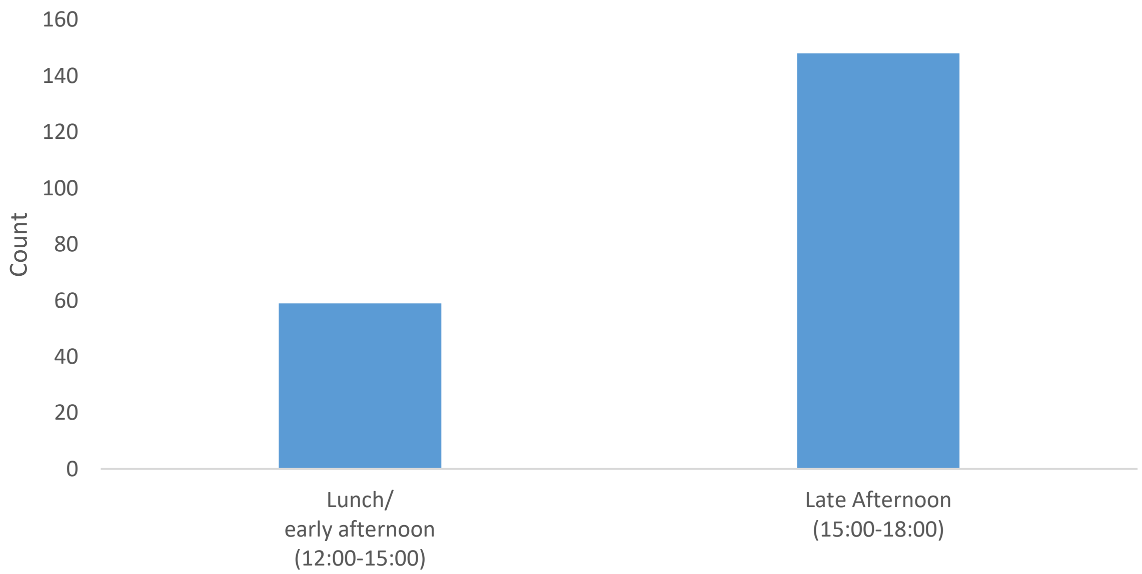
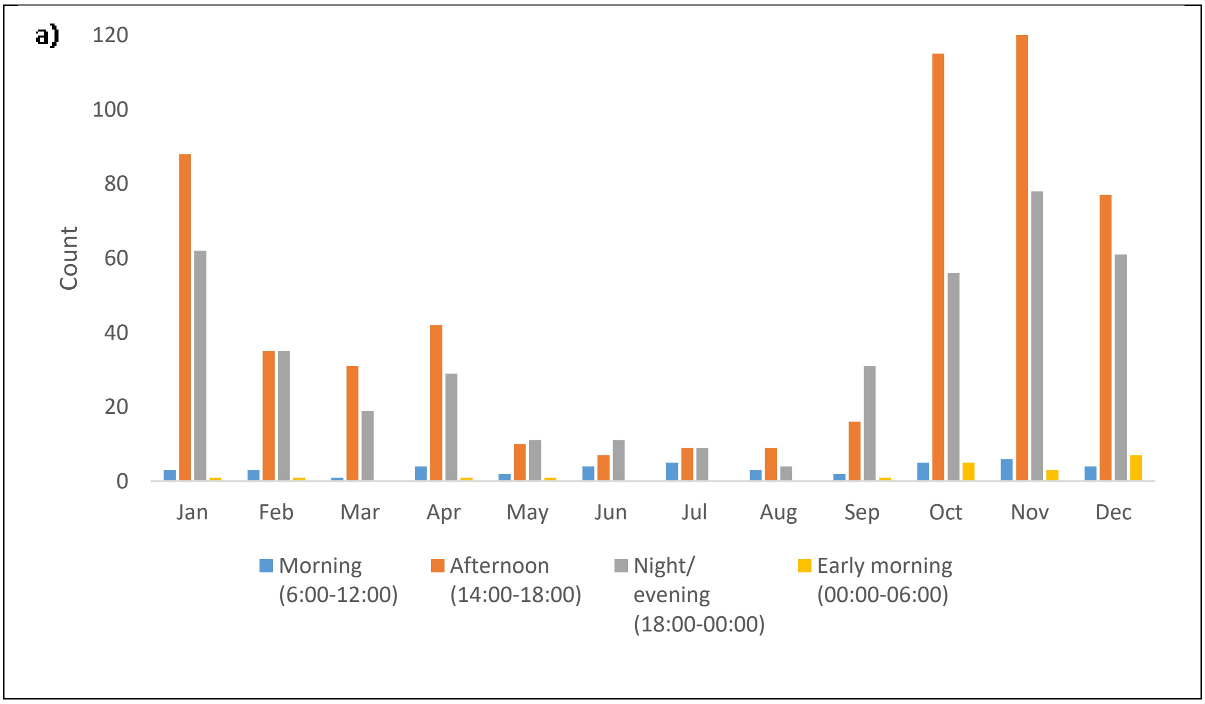


Figure 3.12: *The temporal distribution of newspaper reported hail events from 1900 – 2019, showing the events that occurred in the afternoon in Figure 3.11, further divided into two bins.*

To further, demonstrate the diurnal patterns, Figure 3.13 presents the monthly temporal distribution. Early morning (1.9% of 1048 newspaper articles) hail events are highest in December

(35%), October (25%) and November (15%) (percentages calculated from 1048 newspaper articles with reported time). Morning hail events (4% of all 1048 newspaper articles with reported time) are highest in November (14%), July (9.5%) and October (9.5%) (Figure 3.13a) (percentages calculated from 1048 newspaper articles with reported time). Evening/night hail events are highest in November (19%), January (15.2%) and December (15%) (percentages are of the total reports with reported time); however, hail during the evening/night is dominant in May, June, and September. Afternoon hail events were highest in November (24%), October (20%) and January (15%) (percentages calculated from 1048 newspaper articles with reported time), and dominant in the months of January, March, April, October, November, and December. The distinction between early and late afternoon hail is shown in Figure 3.13b, hail events are reported in the later afternoon in all the months except for June and July, which did not record early afternoon hail. September, however, reported a higher number of early afternoon hail events than all other months.



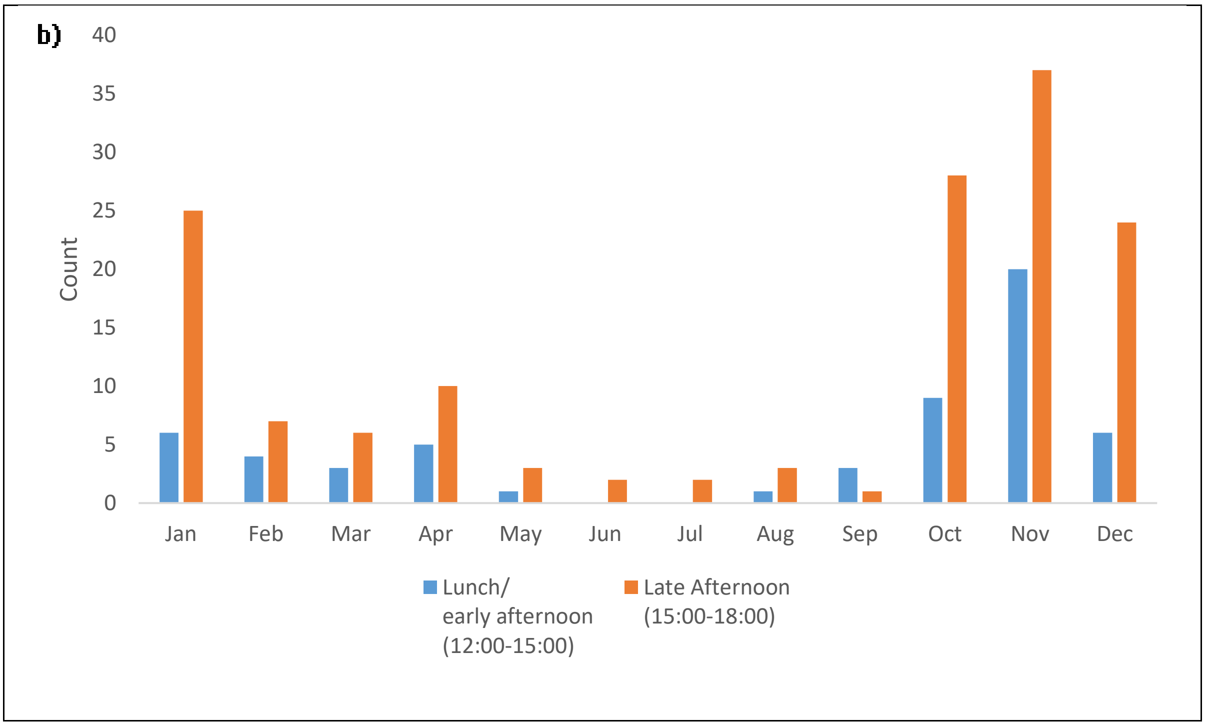


Figure 3.13: *Monthly temporal distribution of newspaper reported hail events from 1900-2019. a) monthly temporal distribution of hail events that occurred in the morning, afternoon, evening/night and early morning. b) Monthly temporal distribution of afternoon hail specifying whether it was in the early or late afternoon.*

Figure 3.14 shows all provinces except for Limpopo mainly experience afternoon hail events, which is dominated by evening/night hail events. The afternoon hail events occur in the late afternoon in all provinces besides the Northern Cape. The Eastern Cape, Western Cape ad Northern Cape do not record any hail events in the early morning, whilst Limpopo does not report any morning events. Majority of the diurnal data reported in the 1048 newspaper articles are for Gauteng (39%), followed by KZN (16%) and Eastern Cape (11%) (Figure 3.14).

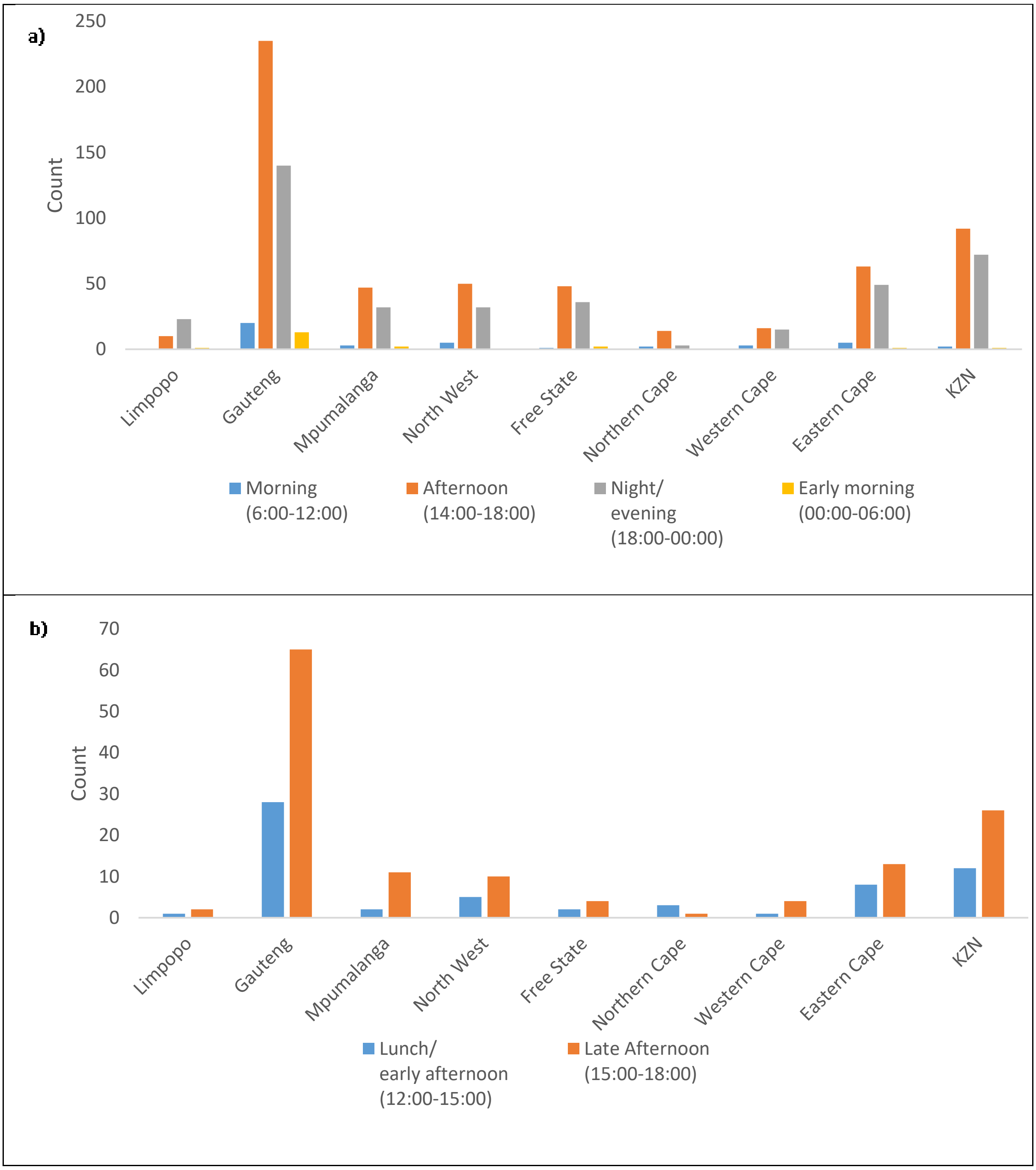


Figure 3.14: *Temporal distribution of newspaper reported hail events per province from 1900-2019. a) temporal distribution of hail events per province that occurred in the morning, afternoon, evening/night and early morning. b) Temporal distribution of afternoon hail specifying whether it was in the early or late afternoon for each province.*

3.1.4 Hailstone sizes

The damage caused to property by hail mainly depends on the size of the hailstone (Palencia *et al.,* 2009). Hailstone growth strongly depends on its path through the updraft and the amount of supercooled liquid water that is encountered (Allen *et al.,* 2020). The largest hailstones in southern Africa usually occur in October, November, and January (Butgereit, 2014). Convective storms that are intense, produce hailstones that are unusually large, or damage agricultural crops or property, as sometimes reported on the news (Tuovinen *et al.,* 2009). Hailstone sizes may thus be used as a relative approximation of updraft velocity.

The size ranges and the number of hailstones, which fall per unit area during a hail event, wind force during the hail event and property of the target, determine hail damage (Bal *et al.,* 2014). In the 1960s, when the Weather Bureau and the CSIR were focussing much of their research on hail, the CSIR developed a hail gun, which was capable of firing hailstones at speeds of 100mph (Rand Daily Mail, 29 November 1960, page 3). The article from the Rand Daily Mail further details that: "The *purpose of the gun was to test the performance of any type of building material under the hailstorm conditions. A report published the tests on a wide variety of materials revealed that there are very few capable to withstand the force of the 1949 Pretoria hailstorm, where the hailstones hit into buildings at 90mph."*

Figure 3.15 shows hailstone sizes reported in the newspaper articles, based on the hailstone scale according to the size diameter category introduced by Bal *et al.* (2014). For this, please refer to Table 2.3 (in chapter 2). The table was adopted because of its wide range of categories, making it more inclusive and detailed in terms of damage. The hailstone size information presented in Figure 3.15 only represents 19.5% (i.e., 383 newspaper reported hail events), as the majority do not mention size. The limited details thus do not permit comparing hail size with time of day. However, it is possible to compare mean reported hail size with the month of the year and geographically.

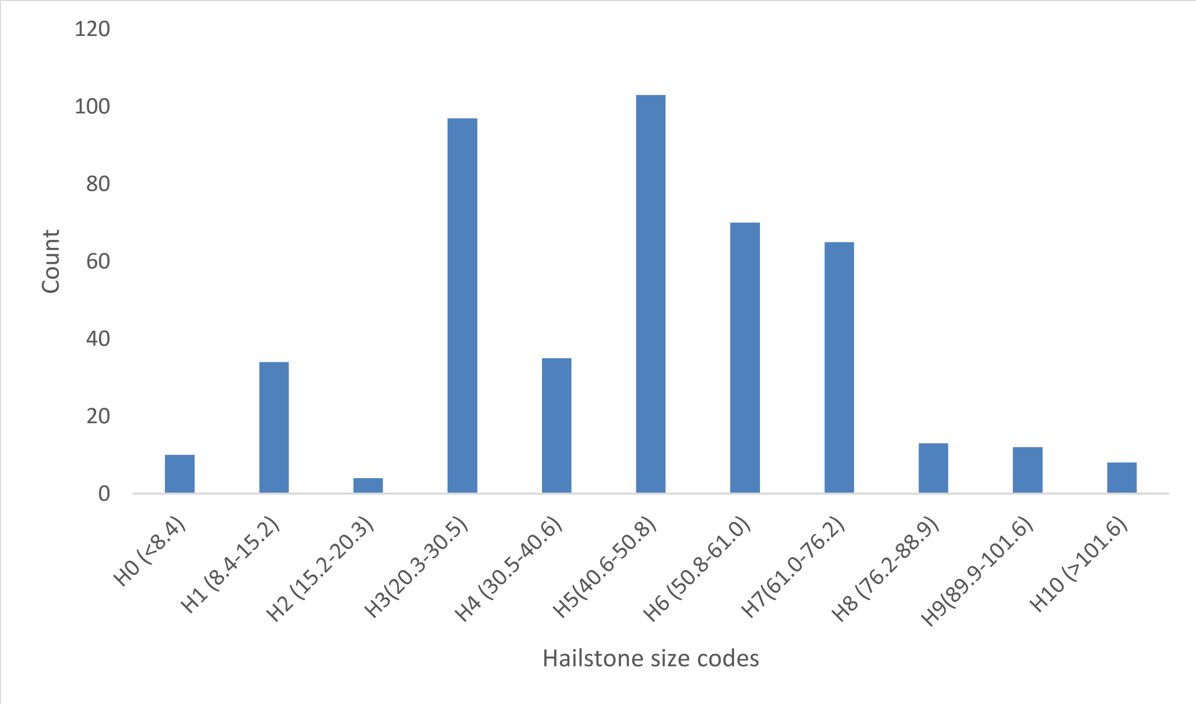
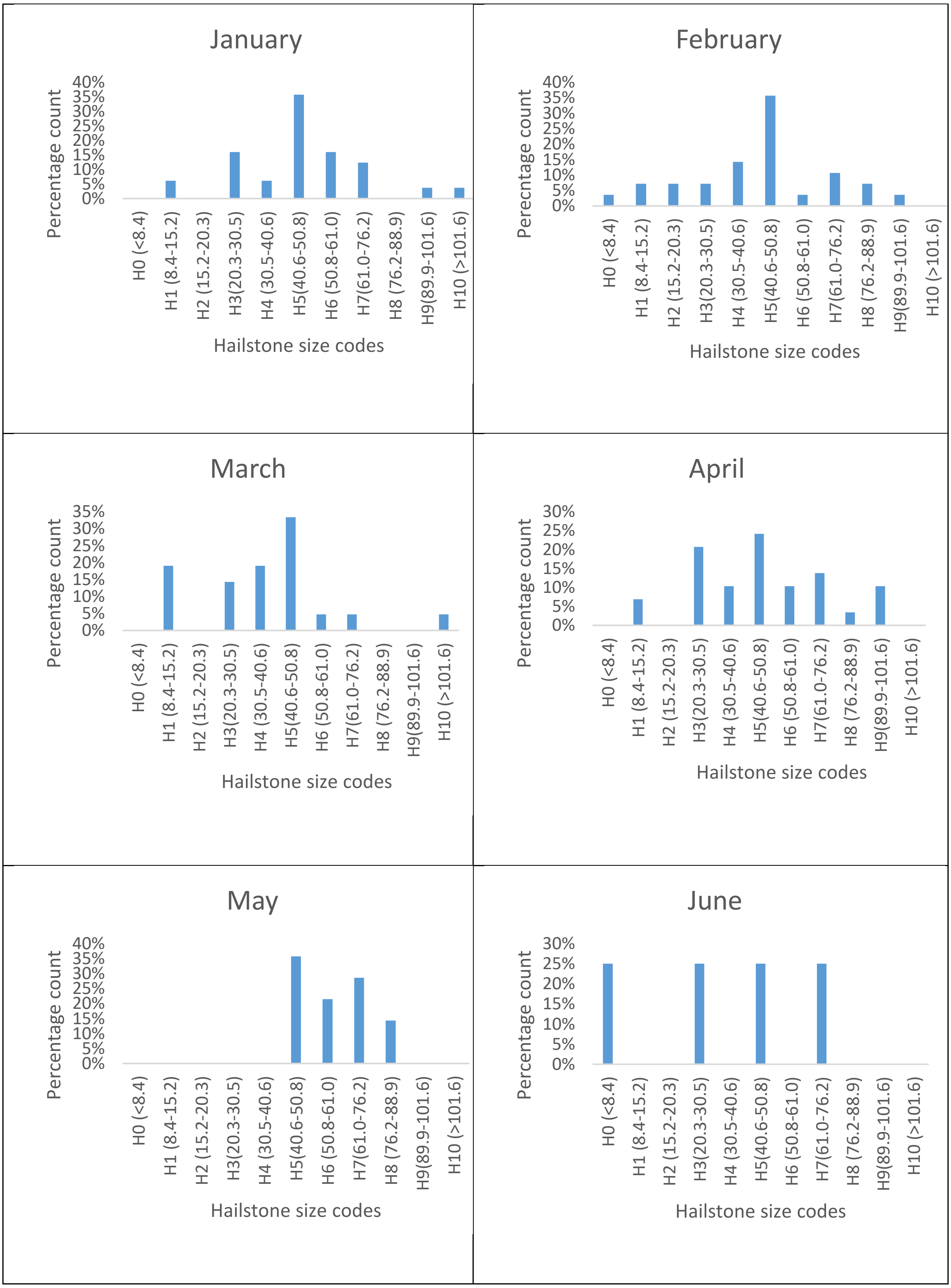


Figure 3.15: *Hailstone sizes (in millimetres) according to the hail size intensity scale adopted from Bal et al. (2014) (see also Table 2.3). The damage caused by each of the categories range as follows: H0 causes no damage; H1 causes slight damage to plants and crops; h2 causes significant damage to fruit, crops and vegetation; H3 causes severe damage to fruits and crops, damage to glass and plastic structures, paint and wood scored; H4 causes widespread damage, glass damage and vehicle bodywork damage; H5 causes wholesale destruction of glass, damage to tiled roofs, significant risk of injuries; H6 causes aircraft bodywork dents and pitted brick walls; H7 causes severe roof damage and risk of serious injuries; H8 causes damage to aircraft bodywork; H9 causes extensive structural damage; H10 causes extensive structural damage and risk of severe of even fatal injuries to persons caught in the open.*

Kinetic energy of falling hail is of importance to the study of hailstone sizes as this is the factor that can determine the extent of damage (Hohl *et al.,* 2002). The most reported hailstone size belonged to the size code H5, which can be seen in Figure 3.15, with a typical diameter of 40.6mm to 50.8mm, equivalent to the size of a tennis ball. The damage caused by H5 is wholesale destruction of glass, damage to tiles roofs and significant risks of injuries. Hailstones of that size develop mostly in the late afternoon when most hailstorms occur; this time of day is when there is peak traffic, which exposes more vehicles to the hailstones. Their exposure can also be due to slow-moving traffic experienced during severe weather. To show that this matters to insurers, an article by Judy Green (2006) stated *"Mutual & Federal, like all insurers, is truly grateful that the Johannesburg hailstorm last April happened at night. The claims total amounted to R50m. Had the heavens opened on a busy day, the damage could have come to 10 times that amount."*

The second most reported hailstone size code is H3 (20.3mm to 30.5mm in diameter), which is equivalent to the size of a nickel or a quarter; however, in newspaper reports it is equivalent to hailstones measuring "*an inch in diameter", "pigeon's eggs"* and *"fowl's eggs"* (see Appendix I). These cause severe damage to fruit and crops, damage to glass and plastic structures, paint, and score wood. Figure 3.16 provides an analysis of which code sizes are most prevalent in given months. January, November, and December have most of the code sizes occurring. Again, notably H3 and H5 are the most frequently reported, followed by H6.

There are only 6 mentions of H10 (1.6% of all mentioned hailstone sizes), all reported before the year 1940, in the months January (three mentions), March (one mentions) and November (two mentions). Mentioned hailstone sizes for the months June, July and August totalled four cases each, ranging from H2 to H7. The 1921-1940 period has the highest reported hailstone sizes (115 reports) dominated by H3 (28%), followed by the years 2001-2019 which is dominated by H5 (44%) (Figure 3.17). There is no gradual increase or decrease in the hailstone sizes through the years, besides the hail size code H5, which increases though each time period (from 6% to 44%) (Figure 3.17).


January
Percentage count
40%
35%
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes
February
Perecntage count
40%
35%
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes
March
Percentage count
35%
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes
April
Percentage count
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes
May
Percentage count
40%
35%
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes
June
Percentage count
30%
25%
20%
15%
10%
5%
0%
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)
Hailstone size codes

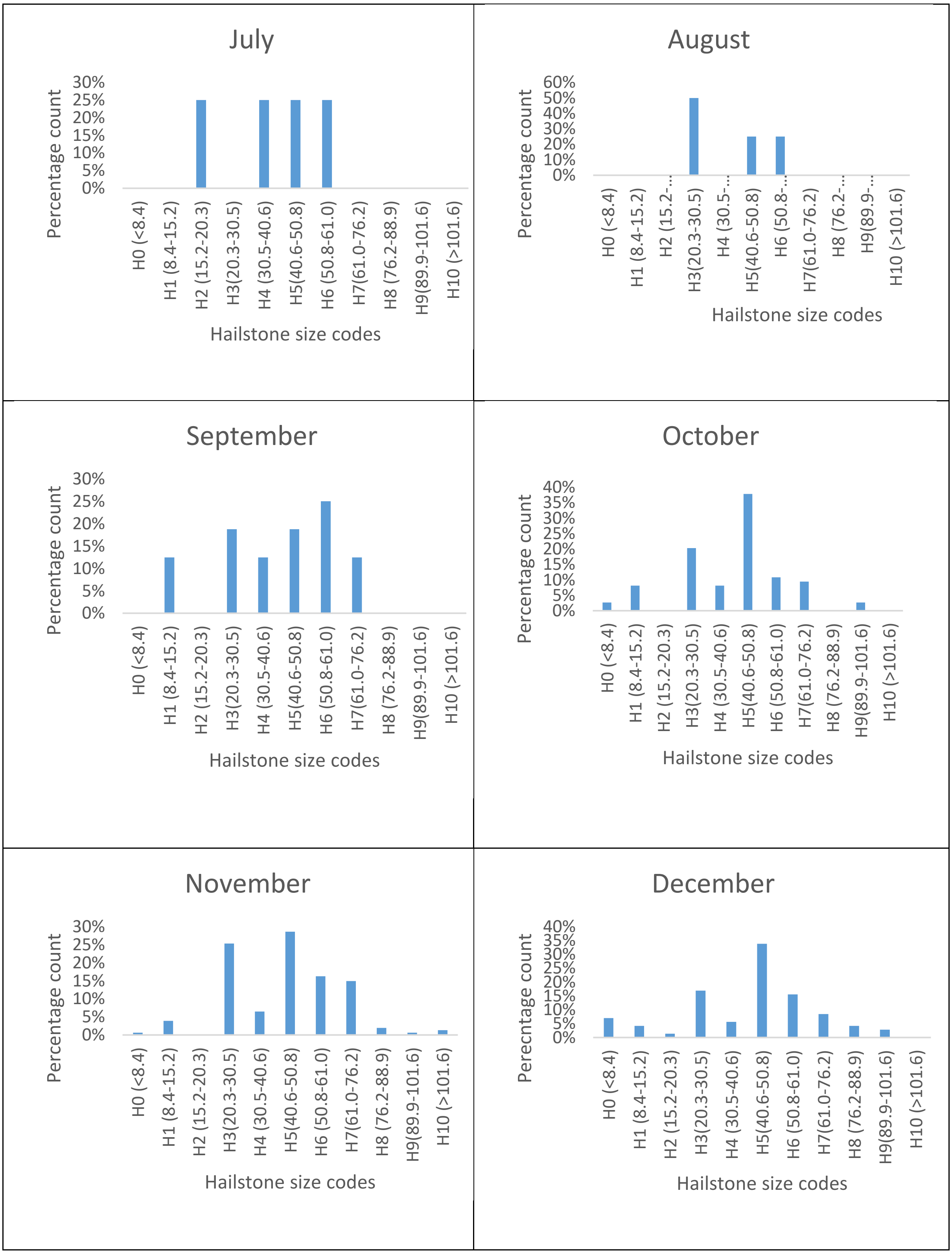


Figure 3.16: *Monthly percentage distribution of hailstone size and relative damage type after Bal et al. (2014).*

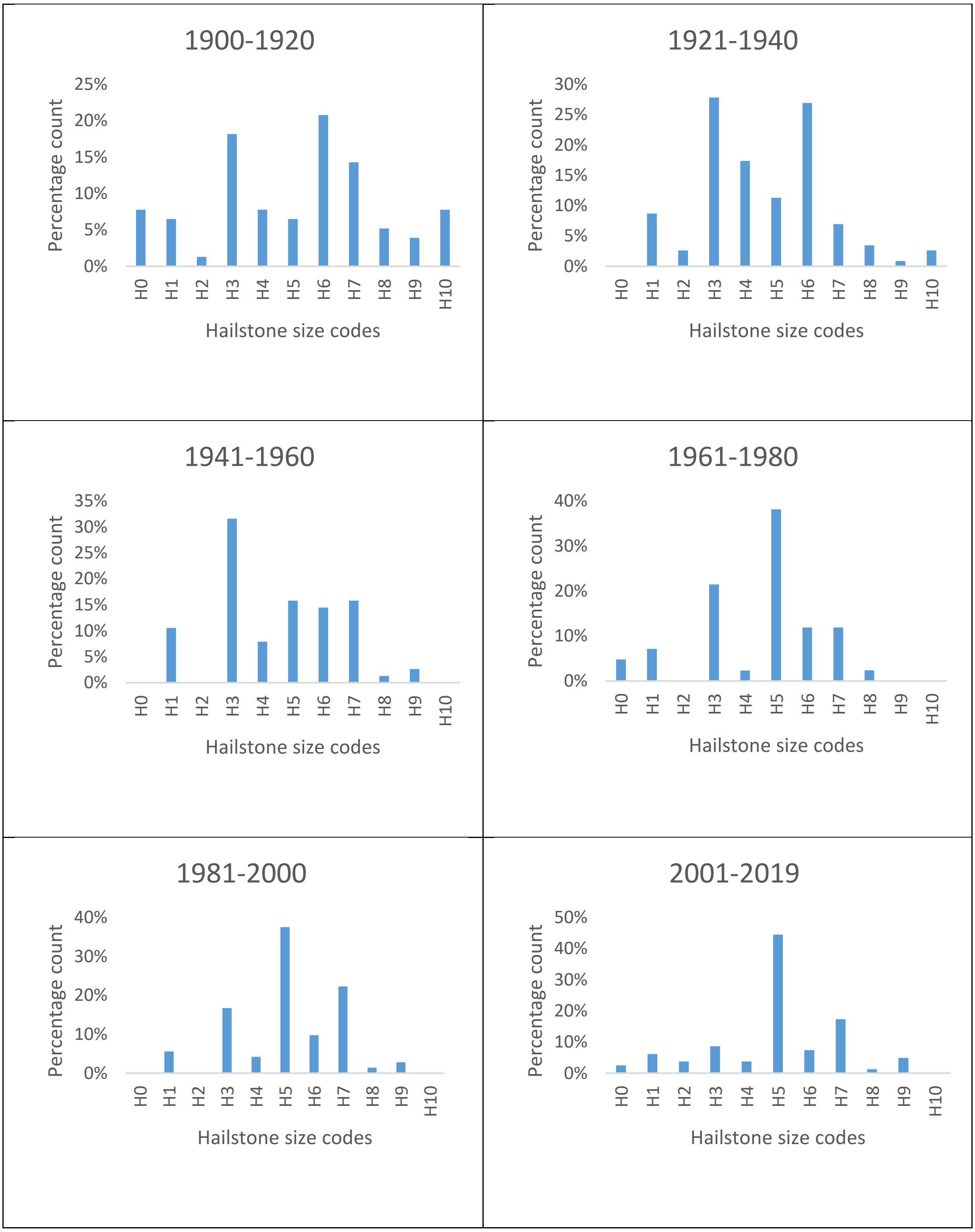


Figure 3.17: *Percentage count of hailstone sizes reported in newspaper events from 1900-2019 in 20-year intervals.*

The geographical distribution of these hailstones, with the hailstone sizes are displayed in Figure 3.18. Gauteng province having the highest number of reports (118 reports), followed by KZN (72 reports). The mapped hailstone sizes represent the maximum hailstone for a particular area, particularly those with repeated occurrences.

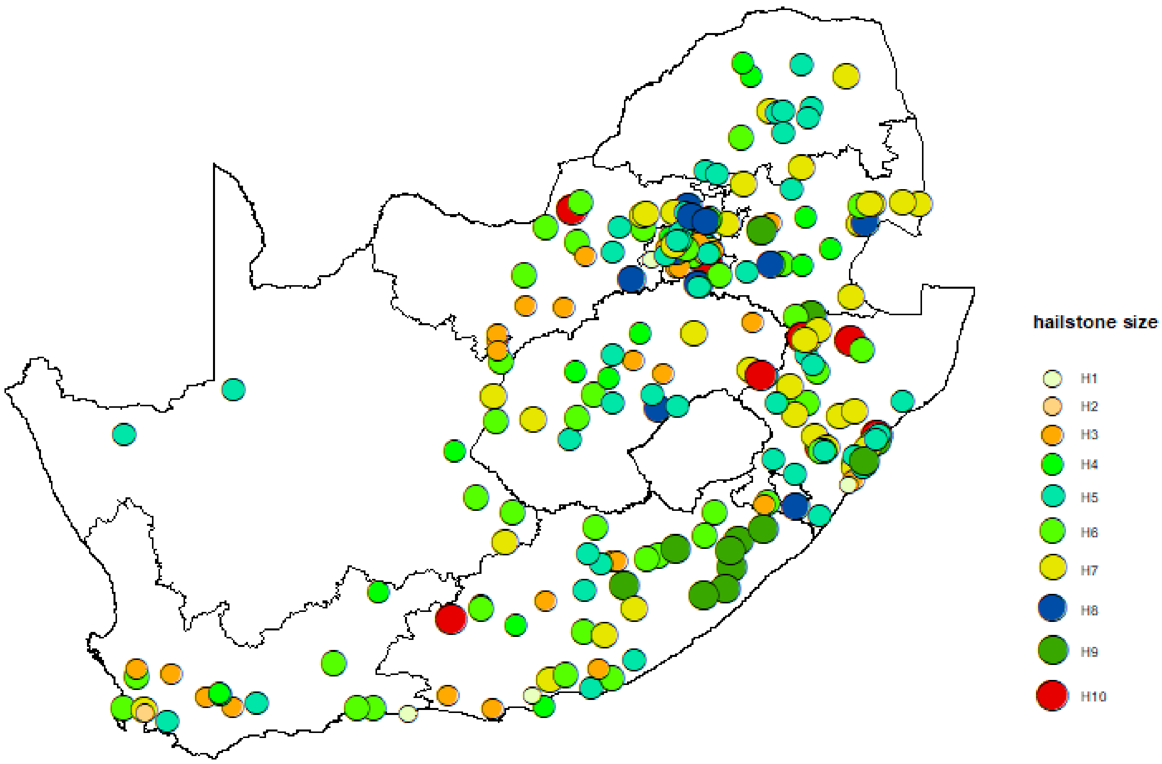


Figure 3.18: *Spatial distribution of hailstones and hailstone sizes from newspaper reported hail events from 1900-2019.*

Hailstone size code H0 was not mapped, based on the lack of damage it causes. The highest numbers of each code size are reported for Gauteng (H0 [40%], H1 [52%], H3 [38%], H4 [35%], H5 [36%], H6 [23%], H7 [31%] and H8 [50%]), H2 was reported in Western Cape (50%) and KZN (50%), H6 (23%) is tied in the Eastern Cape which has the highest reported H9 (67%) hail code size, lastly, H10 (50%) is highest in KZN. Gauteng has two clusters, to the north (Pretoria region) and south (Johannesburg-region) where most of the hailstones and hailstone sizes were reported with repeated occurrences. KZN has technically three clusters: along the coast, Pietermaritzburg region and Newcastle-Ladysmith region; all these regions commonly experience H10 hailstone size classes. The Eastern Cape experiences larger hailstones in the eastern parts of the province. Western Cape has larger hailstones in the eastern parts of the province, even when most hailstone reports are to the west of the province. Limpopo and Northern Cape have lower reported hailstone size classes.

3.2 AREAL DISTRIBUTION OF HAIL

All reported towns mentioned in the articles reported to be affected by hailstorm were plotted onto Google Earth. Figure 3.19 displays all the data points obtained from newspaper articles, detailing significant hail events at particular sites or areas. Appendix 3 presents the monthly distribution of hail events for each of the provinces.

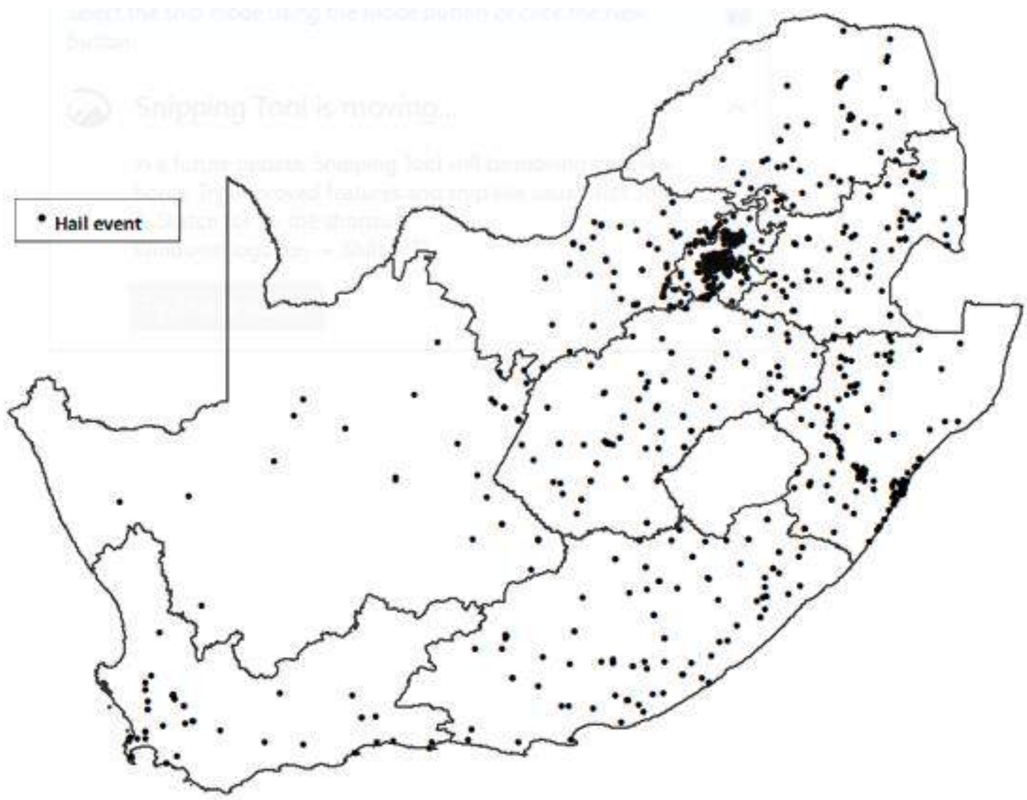
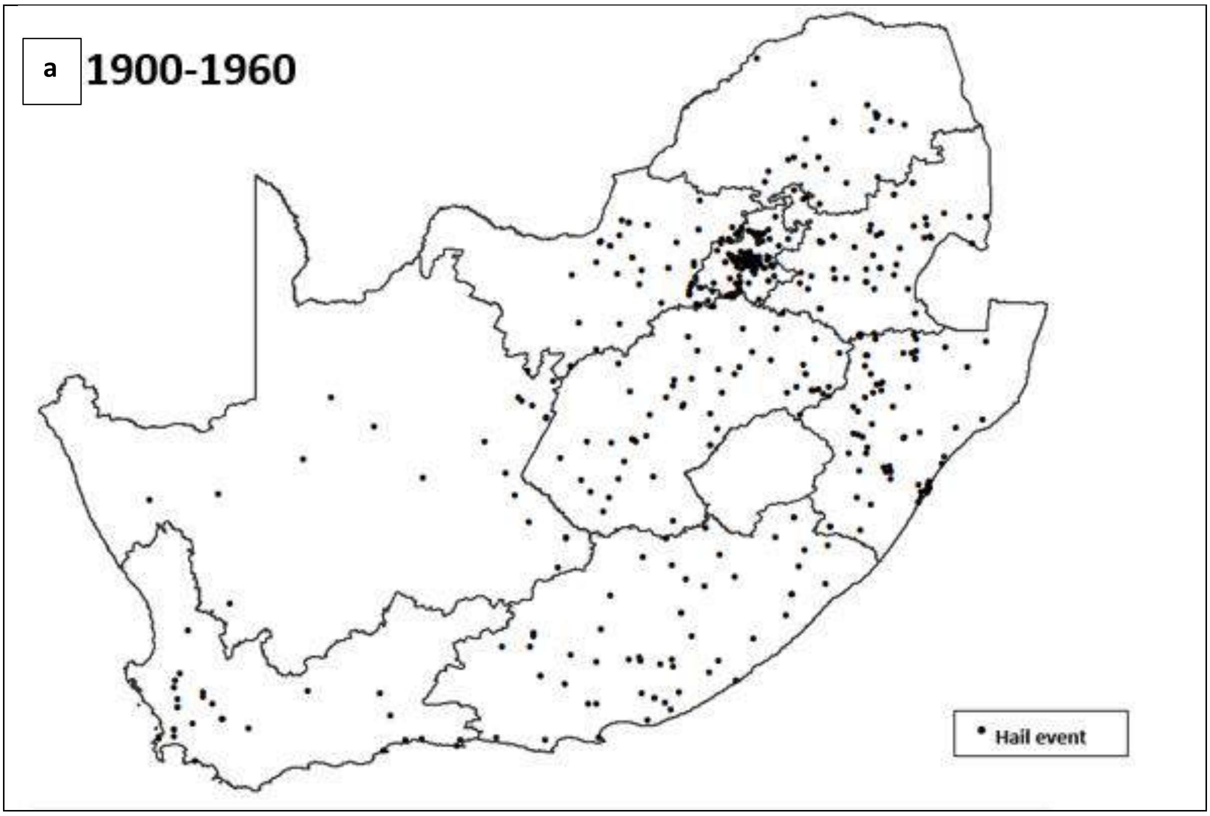


Figure 3.19: *Spatial distribution of newspaper reported significant hail events from 1900-2019.*

Many of the hail events are located in the central and eastern parts of South Africa, with distinct clusters in Gauteng, KZN coastline and Pietermaritzburg (in KZN). The two clusters in Gauteng, to the north and the south of the province, are Pretoria and Johannesburg (including the East and West Rand). In KZN, the clusters are located parallel to the coast, Pietermaritzburg and between Ladysmith and Newcastle. These clusters are located in major towns and cities in their respective provinces. The possible reasons are discussed later in the chapter.

To demonstrate a change in spatial distribution, the data were divided into 1900-1960 in Figure 3.20a and 1961-2019 in Figure 3.20b. The temporal-spatial distribution trend shows a decrease in the overall reported hail events (1122 vs 841 reports) and over western South Africa, with Figure 3.21 showing the aforementioned trend. However, when examining the temporal-spatial distribution of hail across provinces, the trends are more distinct (Figure 3.22 to 3.28) and are further discussed. According to Figure 3.21a, all but Limpopo (+0.2%), KZN (+1.1%), Eastern Cape (1.4%) and Western Cape (+1.1%), have decreased hail reports between the two intervals. Eastern Cape (+1.7%) and Western Cape (+0.72%) are also the only provinces with increase reported hail days (Figure 3.21b).



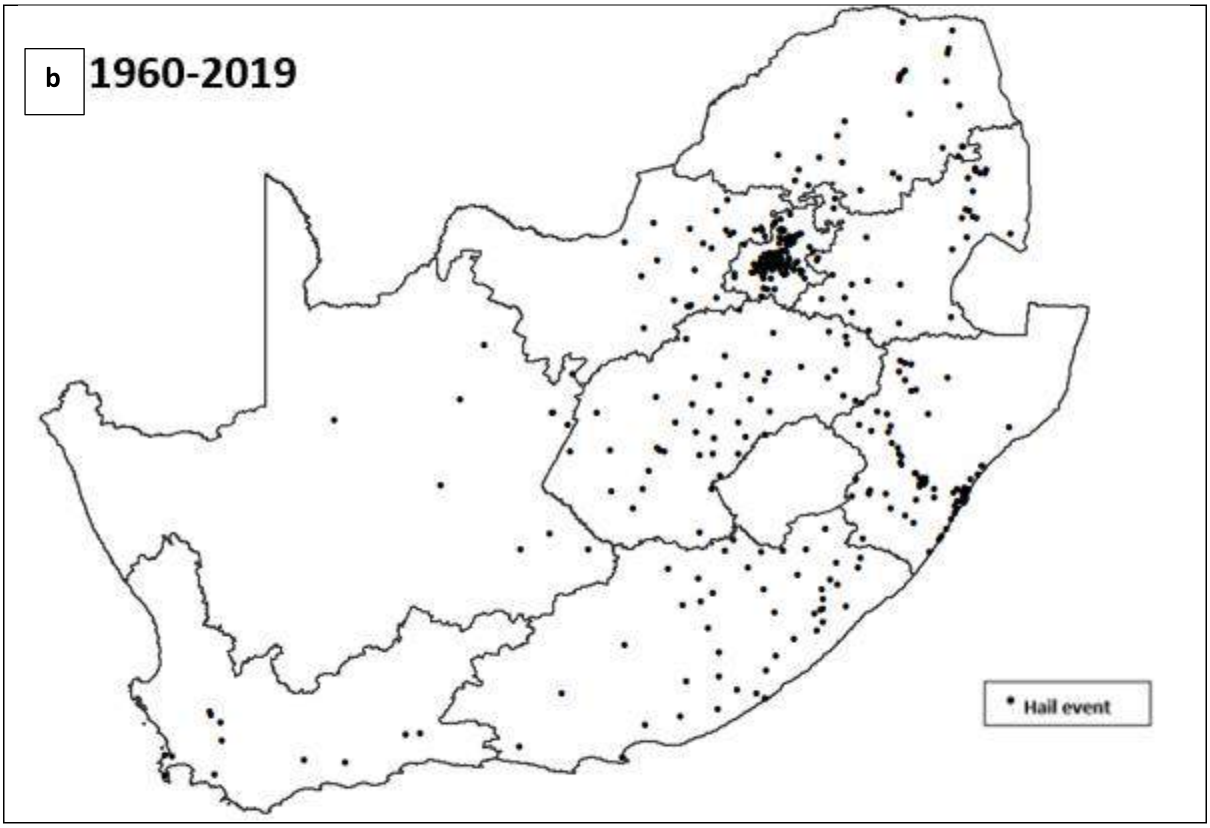
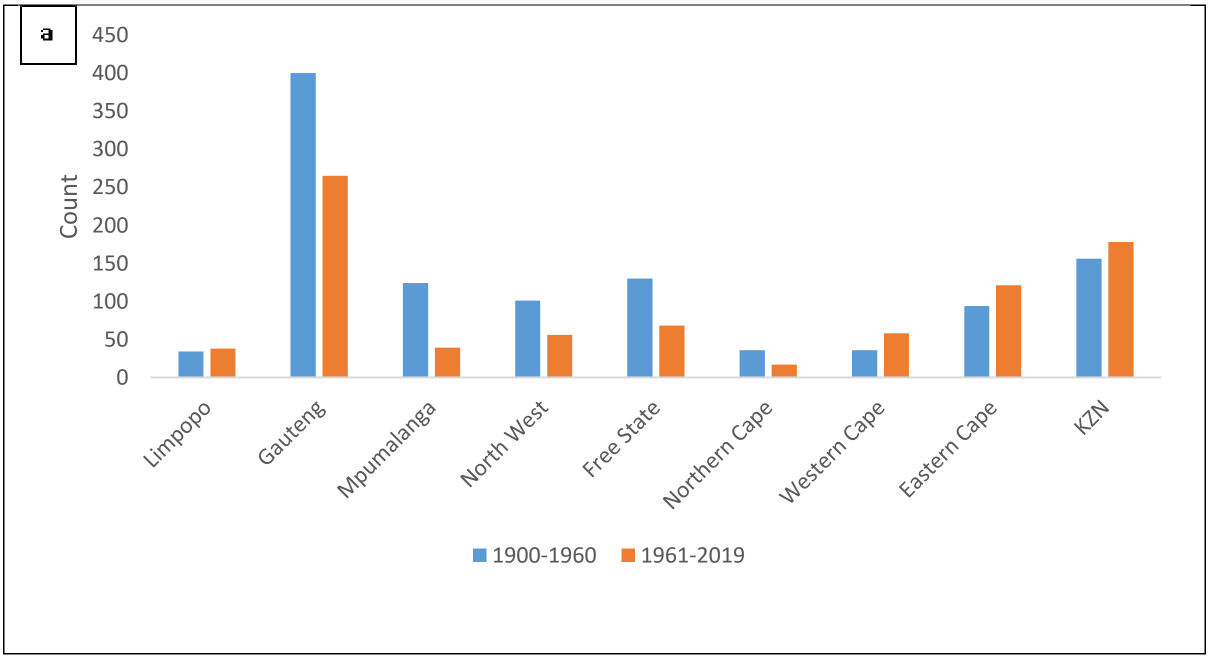


Figure 3.20: *Temporal-spatial distribution of newspaper reported hail events in a) 1900-1960 and b) 1961-2019.*



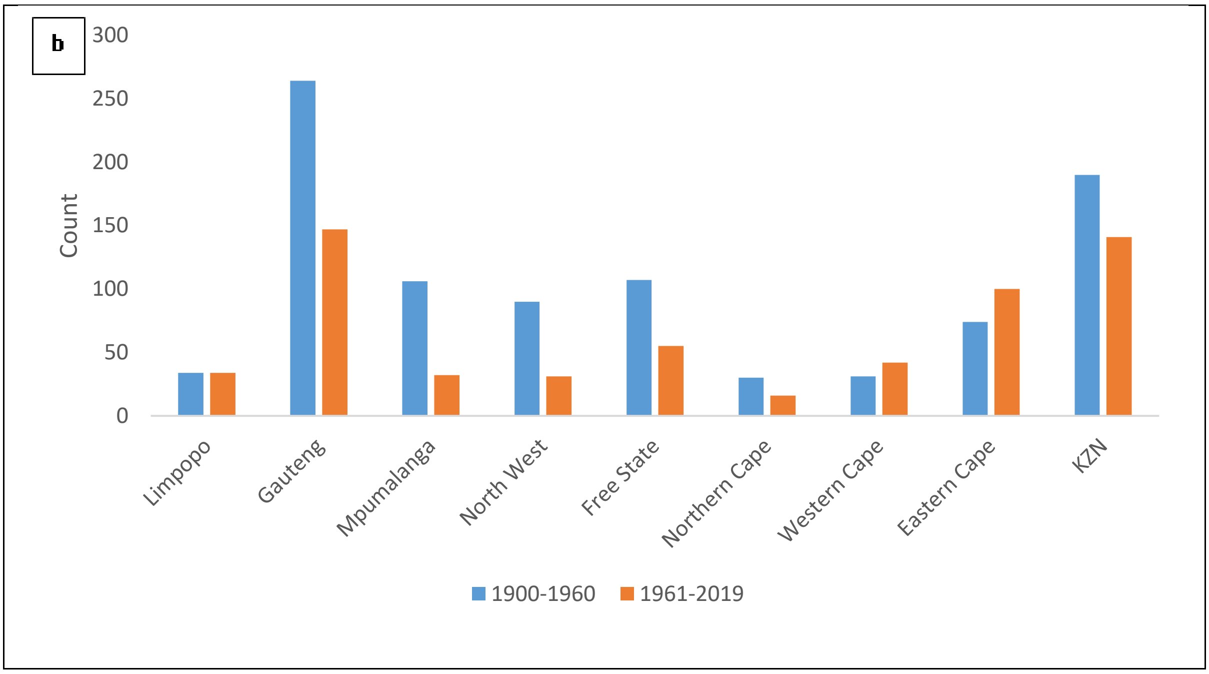
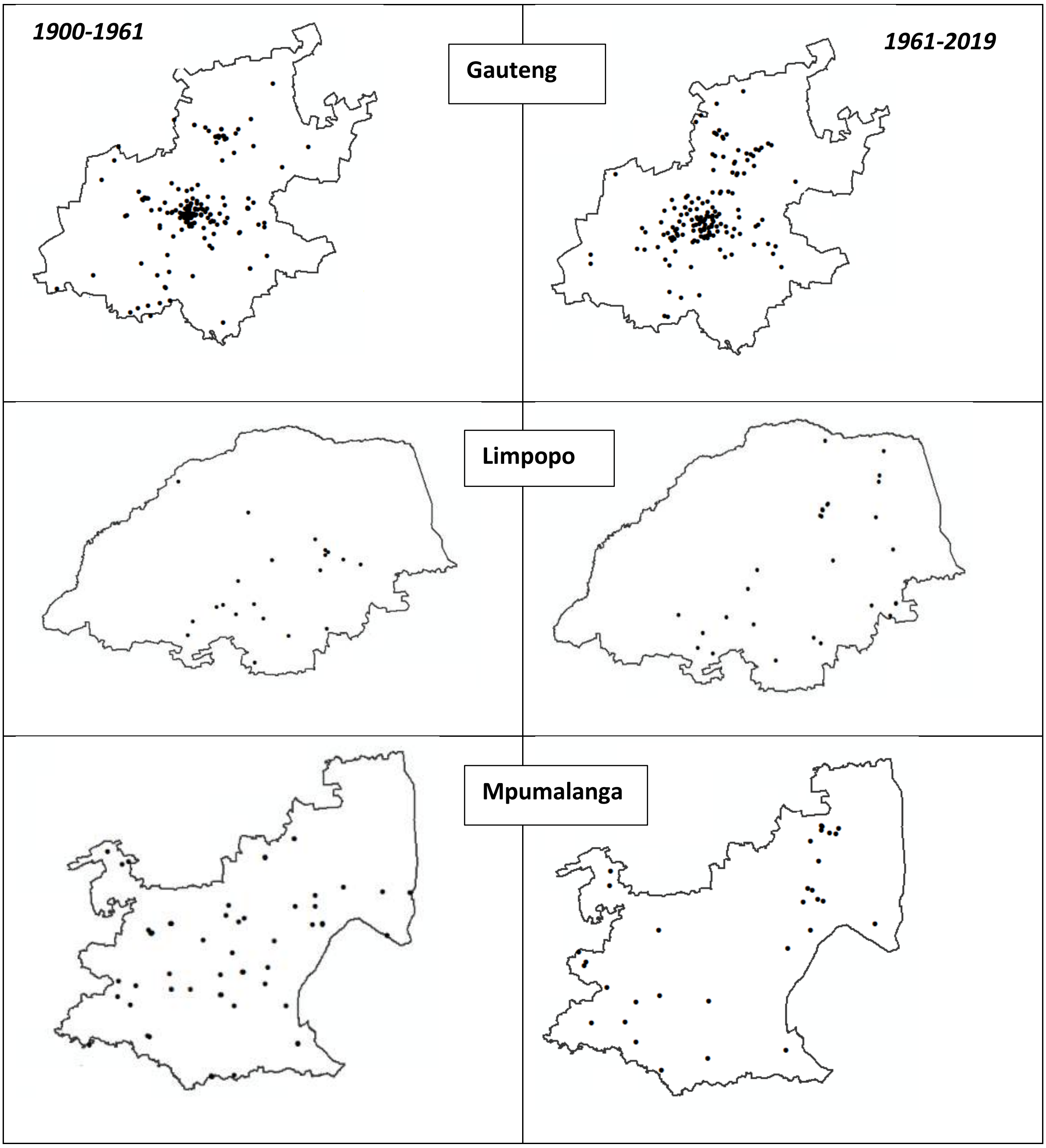


Figure 3.21: *a) Comparison of newspaper reported hail events and b) Comparison of hail days between the periods 1900-1960 and 1961-2019 (as per Appendix 1).*

Olivier (1990) explored the factors (latitude, altitude, and urban effects) that influence the geographical distribution of hailstorms in the former '*Transvaal*', which includes all of Gauteng, Limpopo, Mpumalanga and parts of North West. The results concluded that in terms of latitude- hail day frequencies decreased northwards (towards Limpopo) and the altitude accounted for 50% of the hail day frequency, as topographical features and hail day frequency give a positive relationship. Lastly, urban plume caused the increase in frequency and intensity of thunderstorms and hailstorms. Surface precipitation is likely to further increase under higher aerosol concentrations if air humidity is high, deep, and strong convection occurs (Han and Lee, 2014; Lin *et al.,* 2021). These intensified storms produce more supercooled droplet numbers and mass, enhancing hail embryo formation via rimming (Lin *et al.,* 2021). Figure 3.20 shows the geographical distribution of hail for the above-mentioned provinces.

The hail clusters in Gauteng seem to be associated with elevation, and Johannesburg reporting more hail events than Pretoria. With a decrease in reported hail reports (400 to 265 reports) and hail days (264 to 147 days), there is an increase in reported hail events to the north. This may be due to the increase in urbanisation (and population) between Pretoria and Johannesburg, where Midrand has changed from open fields to a more residential and business hub. This can cause an increase in reports as more livelihood and property is at risk. In the Johannesburg area, there is an increase towards the north-west and more events to the surrounding areas. A change in land-use and population (increase), including the increase in publications based in the province.



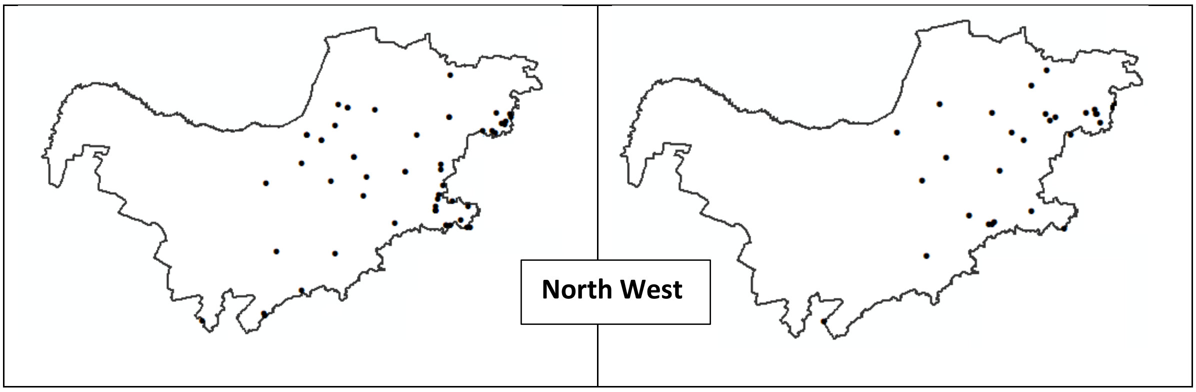


Figure 3.22: *Comparison of the temporal-spatial distribution of reported newspaper reported hail events in Gauteng, Limpopo, Mpumalanga and North West provinces between 1900-1960 (left) and 1961-2019 (2019).*

Limpopo is one of the provinces with the second least hail days (4.5%). There is also a very notable absence of hail events to the west and north-west of the province, as also noted by Olivier (1990). In the left frame, Limpopo hail events were confined to the southeast, with an increase in hail reports to the northeast. The east of Limpopo varies from high mountains (southeast) to low lying areas towards the north. The mountainous regions are where more rainfall occurs due to orographic uplifts. Although the southwest of the province also has mountainous regions, with the Thabazimbi area receiving some of the highest rainfall, there seems to be an absence of significant hail reports from this region (Sikhwari *et al.,* 2022).

Mpumalanga province has a notable difference in distribution, with a decrease in reported hail events towards the interior. The north-eastern parts of the province (Barbeton Makhonjwa Mountains) document the highest hail reports in the region. This area is also reported to have high lightning occurrence, which is a weather type that is compatible with hailstorms (Blamley *et al*., 2017). The western parts of the North West province is mainly a dry, low-lying area, which forms part of the Kalahari Desert and hence has a low occurrence of reported hail events and hailstorms are limited to the eastern parts of the province.

Free State has a fair distribution of hailstorms throughout the province. The eastern part of Free State receives 3 to 5 hail days per year, increasing to 5 days towards the southern and eastern regions (Visser and Heerden, 2000). The pattern seen from the two frames in Figure 3.23 is a decrease in hail days (-26%) to the south and northeast of the province, with most hail days concentrating over the interior.

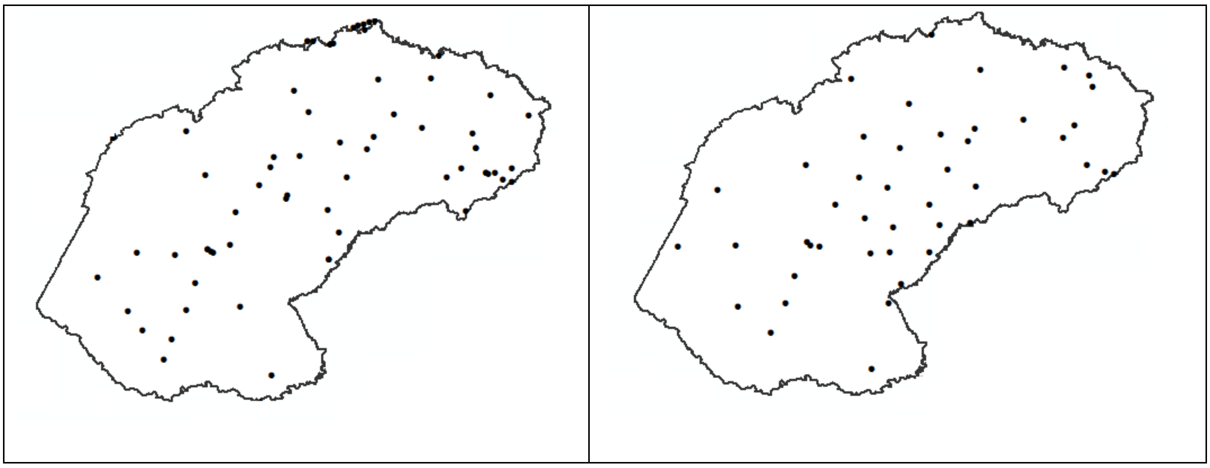


Figure 3.23: *Temporal-spatial distribution of newspaper reported hail events in the Free State province. 1900-1960 (left) and 1961-2019 (right).*

KZN has an increase in hail reporting from the 1900-1960 period to the 1961-2019 period; however, there is a 3.2% decrease in hail days (Figure 3.24). The reporting of Pietermaritzburg hailstorms is very high and attributed to the disproportion between hail reports and hail days. There is an increase in reported hail events towards the north-east of the province, but the cluster pattern remains the same. There is also an increase in hail events along the south coast of the province.

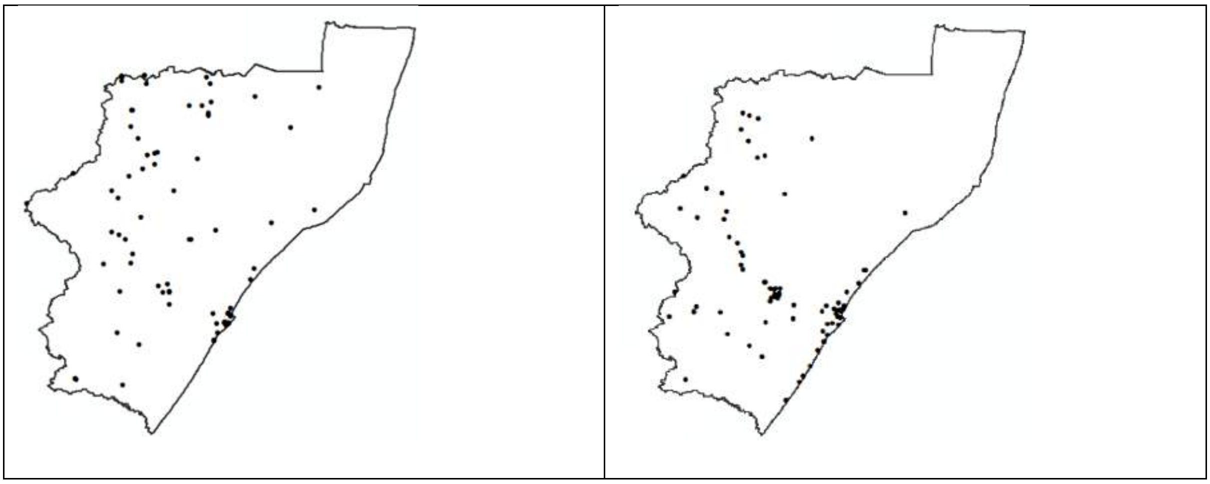


Figure 3.24: *Temporal-spatial distribution of newspaper reported hail events in the KZN province. 1900-1960 (left) and 1961-2019 (right).*

Hail in the Eastern Cape has previously been studied by Perry (1995) and Pyle (2006). Both these studies made use of CAELUM data which is heavily reliant on newspaper reports. Perry (1995) exclusively used CAELUM from 1900-1993; Pyle (2006) uses CAELUM along with other document sources dating back to 1897. The Eastern Cape hail days increased (Figure 3.25) and with hail reports shifting to the east of the province, similar to that Pyle (2006) has found for convective storms. When Pyle (2006) compared reported storms from 1871 to 1991 versus 1992-2006, there was an increase in reporting and the storms shifted to the east; concluding that the latter period is more accurate (Figure 3.25).

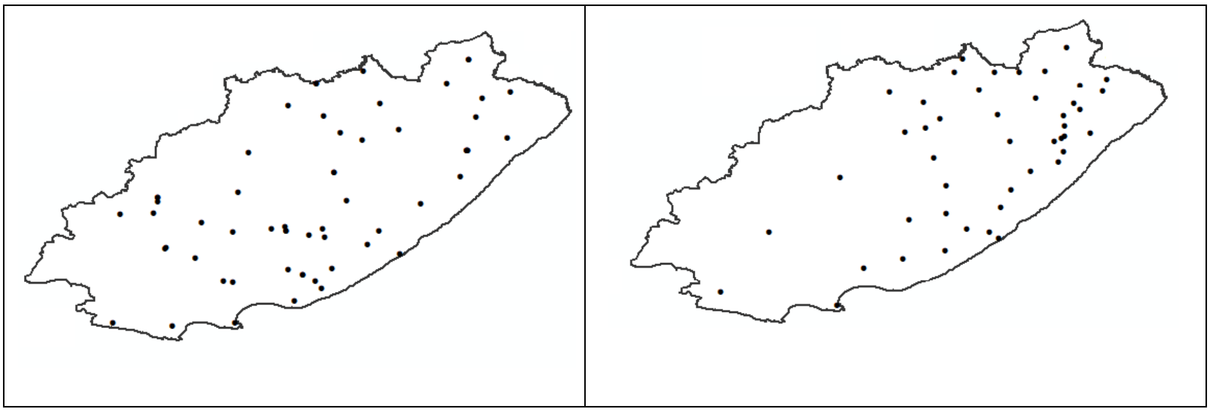


Figure 3.25: *Temporal-spatial distribution of newspaper reported hail events in the Eastern Cape province. 1900-1960 (left) and 1961-2019 (right).*

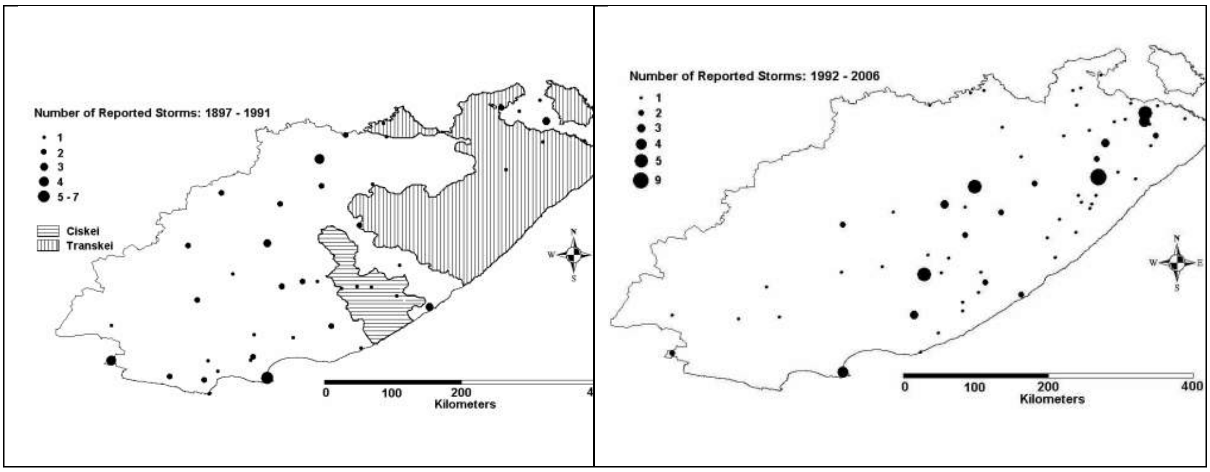


Figure 3.26: *A comparison in the distribution and frequency of severe storms in Eastern Cape in 1897-1991 (left) and 1992-2006(right) (adopted from Pyle, 2006).*

To futher explore the effects of homelands on the reporting of hail events (or the hail events being reported in “known”newspapers by comparing Figure 3.20 to Figure 3.27. In addition to Transkei (east of Eastern Cape), other homelands that may have had an increase in hail reports in natinal media are Gazankulu and Venda in Limpopo and Bophutatswana in the Free State.

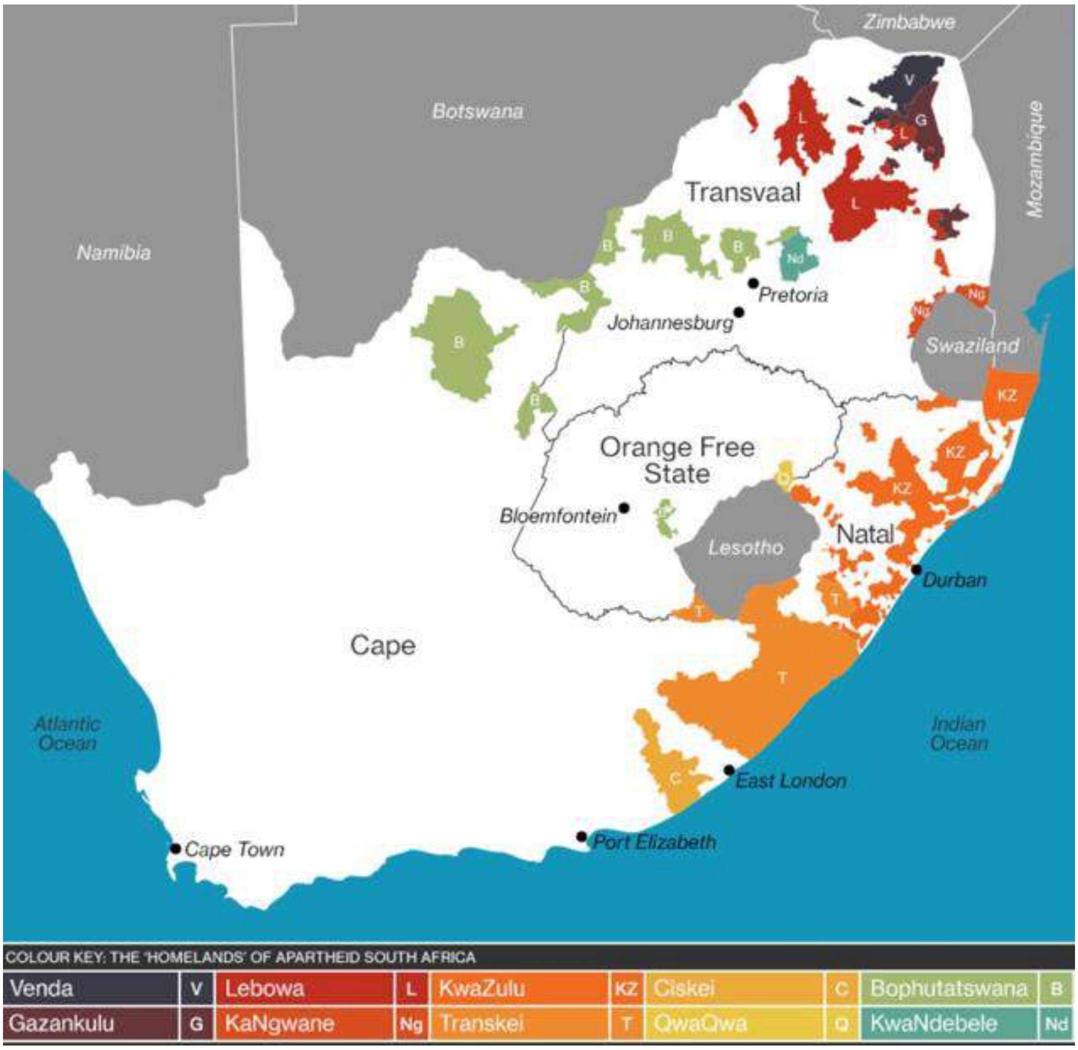


Figure 3.27: *South African provinces and homelands before 1996 (Alexander, 2018).*

The Northern Cape has the least number of reported hailstorms in the country (3% of all hail days). The province is dominated by the Kalahari Desert to its west. With most of the hail reports being to the east, the hail reports to the west are confined to the 1900-1960 period (Figure 3.28). The Western Cape has increased hail reports and hail days (+1.1% and +0.72% respectively). The hail events increase towards the west of the province (by the mountain catchment area where farming is abundant). 43.6% of hail reports in the Western Cape were reported after the year 2000 (with 28 hail days between 2000 and 2019), many of which were about the hailstorms in Ceres in 2013 (Appendix 1).

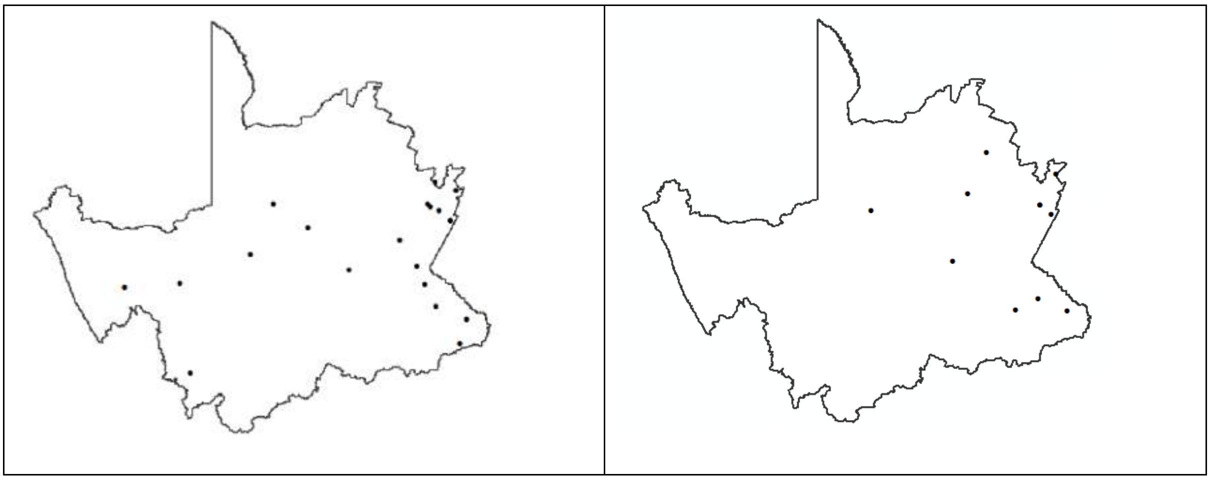


Figure 3.28: *Temporal-spatial distribution of newspaper reported hail events in the Northern Cape province. 1900-1960 (left) and 1961-2019 (right).*

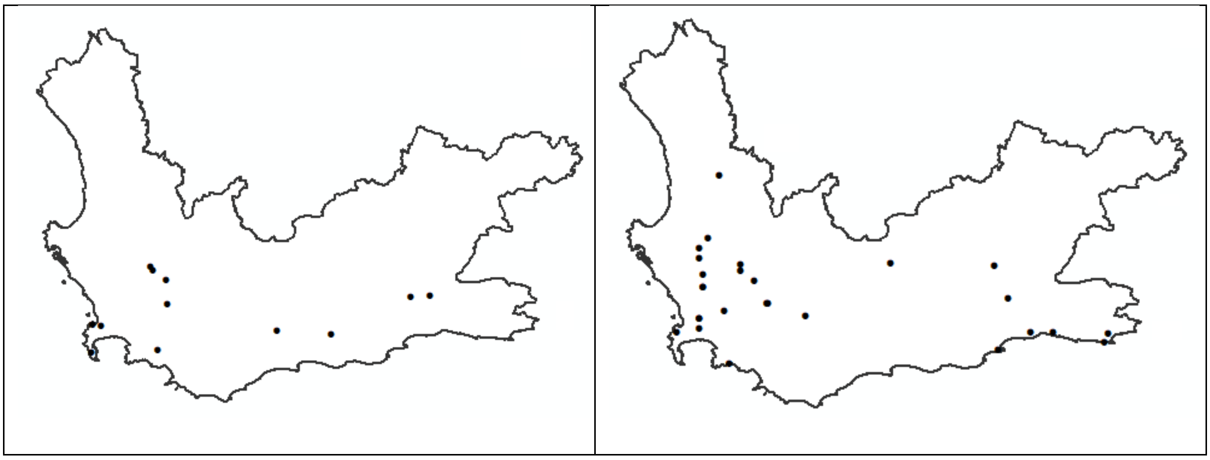


Figure 3.29: *Temporal-spatial distribution of newspaper reported hail events in the Western Cape province. 1900-1960 (left) and 1961-2019 (right).*

4. CONSEQUENCES AND HUMAN RESPONSES

4.1 HAILSTORM DAMAGE AND RISK

Hail frequency studies allow for hail risk detection and does not directly translate to the severity of the hail event. Hence, hail damage characteristics are studied. The extent of damage done by hailstones on crops, animals, people, and infrastructure will be discussed in this chapter, including the responses to the damage by the affected stakeholders (Ntelekos *et al.,* 2009). The sectors most susceptible to hail damage are insurance and re-insurance, as these sectors cover all other sectors affected by hailstorms (Botzen et al., 2010; Wildenboer, 2013). Figure 4.1 highlights all the hail damage cases reported in newspaper articles collected, from which it is evident that crops are by far the most affected. This demonstrates the high impact hail has on agriculture, as its spontaneity leaves no time for farmers to protect their crops and livestock (Bal *et al.,* 2014). However, the total cost of this damage, as analysed and mentioned in the collected newspapers shows that damage to property bares higher consequences. Reported damage due to hailstorms totals R1 287 145 446 for property compared to R392 124 412 for crops from the years 1900-2019. Due to the Rand currency only being introduced in 1961, the amounts reported in pounds prior to its introduction were converted using the historic Rand-Pound exchange rate of 2019 (the latest year of the research). These costs are estimates and true values shown in the collected newspapers.

Insurance claims for natural disasters have been reported in newspapers going back to the 1980s (Bell, 1984). These reports are usually summary totals of disaster events that have taken place. For example, SwissSA Reinsurance reported flood and hail damage in October and November 1984 estimated at R60 million, and this was before damage assessments were completed.

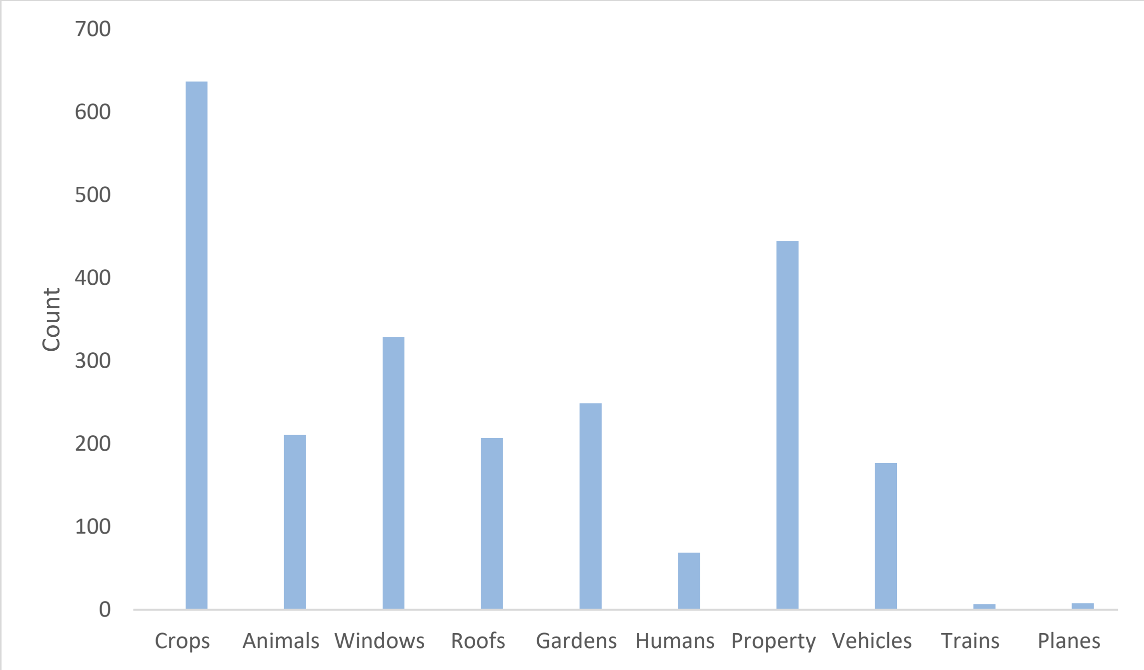


Figure 4.1: *Hail damage data quantified from 'consequence column' resulted in: 637 cases of crop damage, 211 cases of animal injury or death, 329 cases of windows broken, 218 cases of roof damage, 249 cases of garden damage, 69 cases of human fatalities and injury, 455 cases of property damage, 177 cases of vehicle damage, 7 cases of train and 8 cases of plane damage. The data presents newspaper reported hail damage from 1900-2019.*

In 1983, three hail events, estimated by the same company, totalled R23 million; all these events took place in the Gauteng province (Bell, 1984). These costs vary from company to company, and the timeline in which they release the costs. For example, Sentraal Oes Co-Op reported hail damage claims by farmers was estimated to be R23 million in an article dated 12 January 1977, another article dated 14 January 1977 reported the hail damage estimates would be R35 million (van Graan, 1977; The Citizen, 14 January 1977). Both these estimates were the highest claim amounts received by the company at the time.

Insurance claims caused by hail have since grown in number and in resultant costs, with insured assets in hail hotspots attracting higher premiums (Geldenhuys, 2013). The insurance company, Santam, undertook a comparison with hail damage claims - following the Pretoria hailstorm in 1985, 4000 vehicle claims were received with a cost of R15 million versus the East Rand hailstorm in 2012 when 2000 vehicle claims were received with the cost of R28 million (Finance24, 28 October 2012). The costliest hailstorm was that of November 2013, affecting both Pretoria and Johannesburg, affecting property, infrastructure, vehicles, agriculture and causing insurance claims estimating at R1.6 billion (Daily Dispatch, 13 June 2017).

4.1.1 Hail/Hailstorm consequences to agriculture (livestock and crops)

Hailstorm damage to South Africa's agricultural industry is estimated to cost several millions of Rands per year (Santam, 16 October 2015). This also affects areas with low occurrence of hail, as just one hail event can cause economic loss (Púčik *et al.,* 2015). South Africa's agricultural industry has had a vast number of crops being harvested and traded. Through the years, there have been alterations in the types of crops that are traded and the regions in which they are farmed, this will be discussed further in the chapter.

Figure 4.2 considers all reports that mentioned agriculture (crops and livestock) with hail damage from 1900 to 2019; 691 newspaper articles reported on crops and livestock, 35% of all newspaper artcles. The damage becomes more severe when accompanied by heavy rainfall and wind amongst other weather-related phenomena (e.g., lightning). Newspaper articles are not always specific about the type of crop or fruit affected, with some articles only stating that crop and fruit/fruit trees were damaged or destroyed, without providing specific details. Priority has been given to save human lives and livestock during hailstorm events, with damage to infrastructure, vehicles and others being given attention if afforded enough time before the hail fall.

The years with the most crop damage reported are 1940 and 1952, each with 18 mentions. Hailstone/hailstorm impacts on livestock (shown in Figure 4.2) has significantly lower mentions to crops with 211 mentions. The main cause of injury to livestock is the impact of hailstones, with a few reports were lightning was the cause of death for some livestock. Large hailstones can produce significant body injury to livestock, and even death (Bal *et al.,* 2014). Although there are years with no livestock impact reports, some years stand out with a high number of reports, such as 1914 (5.7% of the 211 mentions), followed by 1933 (5.2% of the 211 mentions). With both crops and livestock reported hail-damage, these only serve as proof that such events occurred.

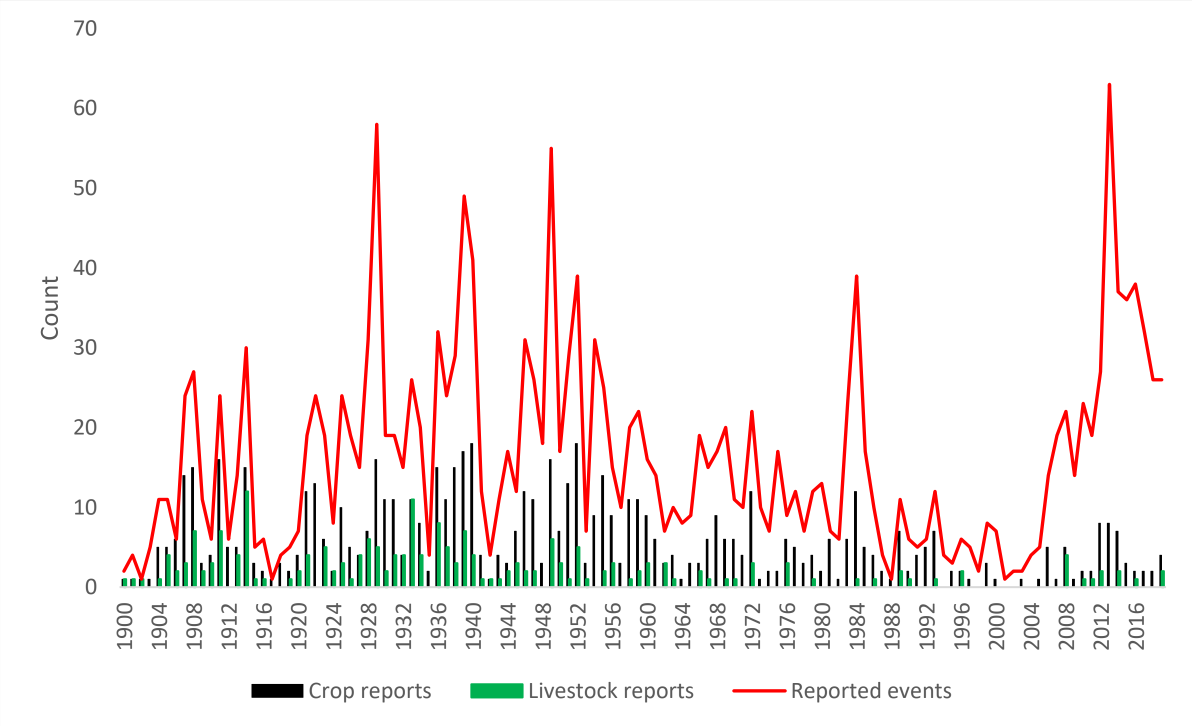


Figure 4.2: *Number of newspaper-reported crop (black bars) and livestock (green bars) damage and hail cases/events (red solid line) per year between 1900 and 2019 (as per Appendix 1).*

4.1.1.1 Crops

Figure 4.3 shows the type of crop damage described in Figure 4.1, representing 637 mentions. These were then divided into fruits/vines which describe fruit, fruit trees and grape vines being damaged or destroyed (293 mentions), vegetable/grains which described all vegetable, grains, and seedlings (294 mentions), gardens describes both private and public gardens (249 mentions) which would sometimes be described and trees (167 mentions), where tree damage would be described.

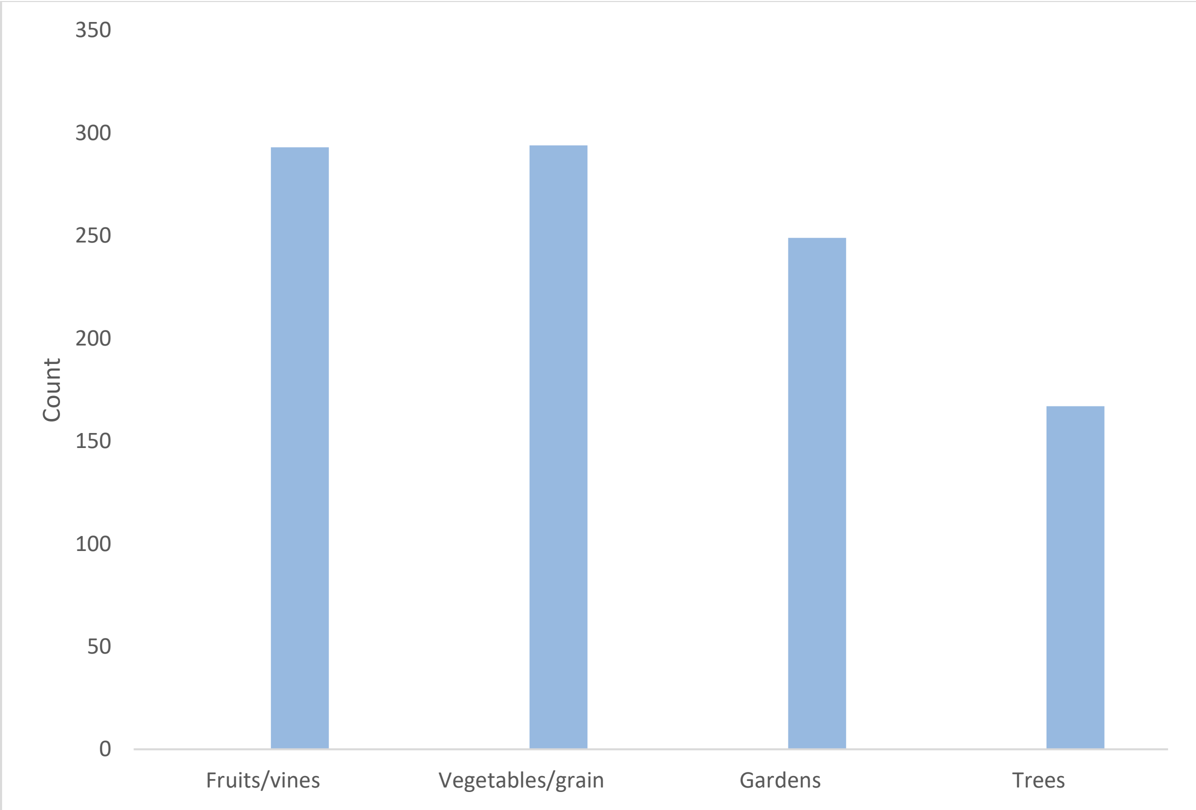


Figure 4.3: *Crop damage done by hail/hailstorms. Crops category divided into 4, namely fruits/vines, vegetable/grains, gardens, and trees.*

Table 4.1 provides specific descriptions from newspaper articles that reported damage, the fruit mentioned was the type of fruit matching these descriptions. Hail damage to fruit, fruit trees, vines and orchards were mostly described as damaged, ruined, destroyed, suffering severely, or flattened in newspaper reports. Many of these, did not mention the type of fruit, but merely the damage overall; for example, "*damage to fruit trees*…" (Rand Daily Mail, 10 October 1977) or "*orchards were ruined…"* (Rand Daily Mail, 14 December 1956). A few articles included the description of the tonnage that was lost, or the areal extent of loss.

Damaged fruit trees had their branches, bark, foliage, and leaves stripped or damaged. This type of damage to trees affects its ability to gain nutrients and further the ability to bear valued fruit (Mauk and Shea, 2002). Damage to foliage can cause trees to be vulnerable to weeds and decrease the chances of pollination if the plant is at its growing stage (Schubert, 1991; Hatfield and Prueger, 2015). The recovery of citrus trees can take from three to five years (Morgan *et al.,* 2009; Geldenhuys, 2013). Even with only few fruits described as damaged, the remaining fruit can decrease in value (Rand Daily Mail, 23 November 1920).

Table 4.1: *Type of damage reported with regards to fruit, vines and fruit trees from newspaper reported hail events from 1900-2019.*

Type	Damage
Fruit	
Apricots, peaches, pears, oranges, apples, kiwi	Knocked off their trees/ battered/battered to the ground
Pears	Young buds damaged/ early fruit destroyed
Plums, yellow peaches, nectarines, pears, peaches, citrus	Damage to ripened fruit/ damaged
Apples	Destroyed during harvest
	Smashed
Citrus	Cut into pieces
Plums, apples, pears, stonefruit	Reduced production
Vines	
Grapes	Shed their bunches/knocked off vines
	Twisted
	Vines handicapped
	Cut down/ large branched cut off
	Reduced production
Fruit trees	
Young oranges, naartjies, lemon	Stripped of their full-grown yields/ stripped bare
Pines, naartjies, citrus, peach	Blossoms damaged/partly damaged
	Branches were twisted, foliage and leaves stripped
	Bark/ small branches stripped
	All fruit knocked off/ lost all their fruit

Hail damage affects field crops and vegetable crops more than fruit (Figure 4.3). The overall damage descriptions for crops were not very specific to the individual crops (Table 4.2). Similar to fruit descriptions, most of these crops were described as damaged, ruined, destroyed, suffering severely, or flattened in newspaper reports. The amount of crop loss is described in bags, in some instances, not mentioning the type of crop.

Table 4.2: *Type of damage reported with regards to fruit, vines and fruit trees from newspaper reported hail events from 1900-2019.*

Type	Damage
Field crops	
Maize, tobacco, cotton	Torn to shreds/beaten down/cut into pieces
Wheat, tobacco, maize, oat	Severely damaged/ruined
Grain	Flattened
Vegetable crops	
Potatoes	Growth affected
Tomatoes, small vegetables, watermelon	Cut/ cut into pieces/ battered down
Gardens	Flattened
	Pounded to pulp
Cabbage, lettuce, lucerne	Damaged; bust open
Root crops	Foliage damage
Grass	
	Uprooted/ bare

Both fruit and crops relating to hail damage have been studied in South Africa and other parts of the world, but the main focus has been on field crops. Studies have used satellite imagery to identify damaged areas for crops such as potatoes (Zhou *et al.,* 2016), maize (Zhao *et al.,* 2012), wheat (Singh *et al.,* 2017), cotton (Yue *et al.,* 2019; Yang *et al.,* 2021) and insurance claims (Carte, 1967; Young *et al.,* 2004; Botzen *et al.,* 2010). Other research has been broader, investigating hail damage to crop or agricultural loss in general (Olivier and van Rensburg, 1992; Botzen *et al.,* 2010; Bal *et al.,* 2014; Rao *et al.,* 2014; Bell and Molthan, 2016; Bal *et al.,* 2017; Prabhakar *et al.,* 2019). Hail damage to fruit and vegetables resemble bird pecking, lesions, scars and defoliation and other damage on both young and mature fruit (Rattanpal *et al.,* 2017). Standing crops usually exhibit broken stems, heads being broken and grain shattering (Rao *et al.,* 2014). The damage does depend on the growth stage, hailstone size and speed (Bal *et al.,* 2014). Physical damage can be seen immediately, but some fruit and vegetables that are not immediately written off are seen by deformities when fully matured (Rao *et al.,* 2014).

After hailstorm damage, surviving trees and crops are susceptible to infections and diseases. Therefore, loss can be immediate or developed through time. The agricultural losses can be in the form of financial loss, investment losses, awaited harvest and job loss. Large-scale hail-crop damage can also cause market shortages, simultaneously affecting the prices (Crotty, 2014; West, 2016).

4.1.1.2 Livestock

Hail impact on livestock has not been exclusively studied in literature; rather it has been combined with studies investigating hail impact to agriculture and weather to agriculture (Baker, 2012; FAO, 2007). More specific impact on livestock can be found in papers by Schmidt *et al.* (2000), Bal *et al.* 2014) and Rao *et al.* (2014). Injuries, deaths, and the number of deaths of livestock due to hail impact is tabulated in Table 4.3. Sheep and poultry/birds were most affected with 107 and 108 newspaper article mentions respectively. Their deaths were also the highest in number, totalling 16817 and 4960 respectively between 1900-2019. These values were not included in Figure 4.4 due to the disproportion to other casualties. The quantity of sheep owned by one farmer compared to other livestock is generally higher than other types of livestock and made more vulnerable when the sheep are shorn. Another loss pertaining to sheep is the wool, when a sheep dies the wool cannot be collected. The size and exposure of poultry and birds to atmospheric weather conditions is also a factor to their large number of deaths. Fowls were the most birds reported to be killed (some specified to be on trees or nests). Other poultry mentioned included hens, turkeys, and ducks and ostrich. The majority reported these as ‘poultry or birds injured’ without any specifications.

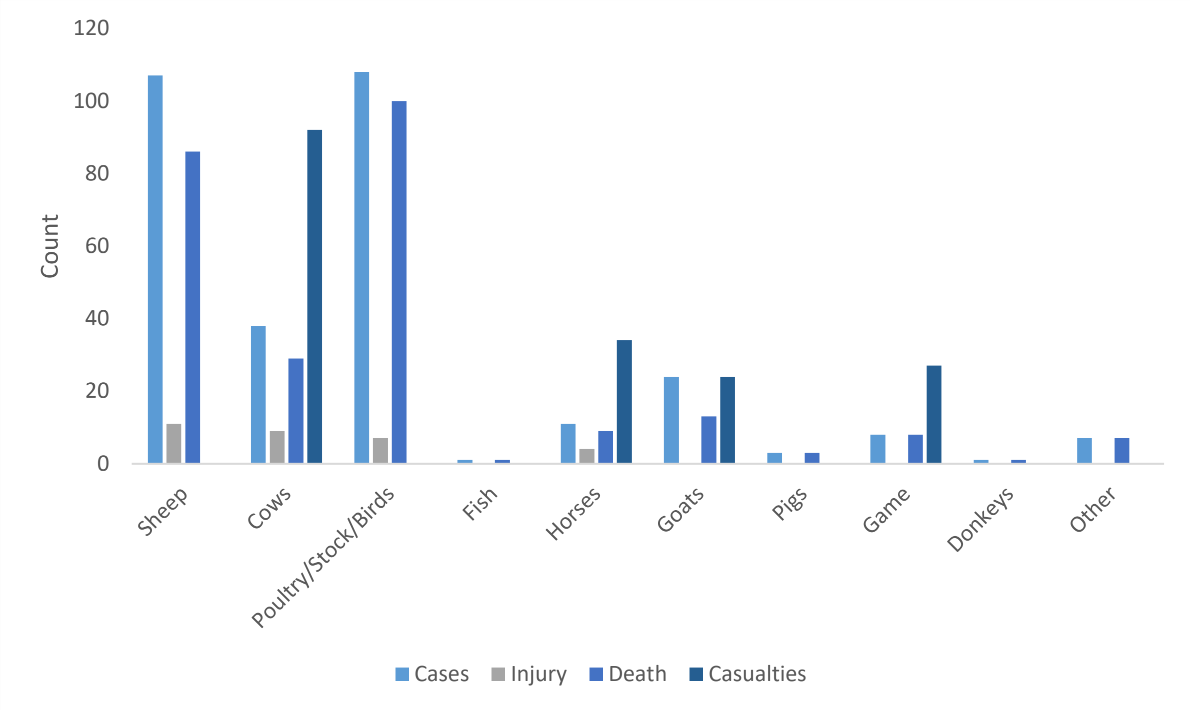


Figure 4.4: *Comparison between the number of reports on the impact of hail (cases), injuries, deaths, and casualties due to hail in newspaper reports from 1900-2019.*

Realistically, larger livestock such as that mentioned in Table 4.3, cows, horses, pigs, game, and donkeys are more prone to injuries than death, however, their deaths are more frequently reported. The injuries would result from stampedes that would occur in the shelters when the deafening sound of hailstones places animals in distress (Rand Daily Mail, 2 January 1905; Rand Daily Mail, 12 February 1936). Only two such cases were reported in the collected newspaper articles, but it can be assumed more of such occasions have occurred (Rand Daily Mail, 12 February 1936).

Fish, though hardly mentioned, have been reported to be killed by hailstones. The first report was in Rand Daily Mail (17 January 1905), where fish in a river were believed to have been killed by hailstones, which collected as high as 0.9 to 1.8 meters on the riverbanks. The fish affected ranged from barbels (2-20lb.), yellow fish (half-15lb.) and all sizes of mudfish. Rand Daily Mail (14 November 1942) also reported hailstones collecting in a fishpond until the fish disappeared. In Rand Daily Mail (15 November 1963), an angler noticed that trout would go missing every time a hailstorm occurred. His theory was that they succumbed to the sudden drop in water temperature. The theory is correct as hailstorms have the ability to cause a sudden drop in water temperature, which is one of the causes of fish kills (Herman and Meyer, 1990; Grant *et al.,* 2014). Bal *et al.* (2014) described the type of damage to fisheries to include migration, damage to fishing structures and impacts of microalgae and pathogens.

Animals in 'other' include were animals such as dogs, reptiles, turtles, hares and meercats, with deaths not specified. Game mentioned included springboks, bucks, cheetahs, and impalas. Hailstones can also cause damage to animal shelter; a bird aviary was damaged and the ability of hailstones to perforate iron or corrugated iron roofs can cause injuries and deaths indirectly.

Table 4.3: *Type of damage to livestock in newspaper-reported hail events from 1900-2019.*

Type	Cases/events	Injured	Deaths	No. of deaths	Damage descriptions
Sheep	107	11	86	16817	Cut and bleeding; lamb brains bashed; lacerated; broken legs; eyes knocked out/blinded
Cow	38	9	29	92	Cut and bleeding; lacerated; bruised during stampedes to safety; hide knocked off
Poultry/Birds	108	7	100	4690	Blind, eyes knocked out
Fish	1	1	1	Not specified	Hailstones filled up a pond
Horses	11	4	9	34	Fractured ribs; eye damage
Goats	11	4	9	34	Not mentioned
Pigs	3	0	3	24	Not mentioned
Game	8	0	8	27	Not mentioned
Donkeys	1	0	1	0	Not mentioned
Other	7	0	7	0	Not mentioned

Birds, livestock, and other animals are typically among the devastation as they are unable to seek adequate shelter under such weather conditions (Tuovinen *et al.,* 2018). After a severe hailstorm, birds have been found lying dead or injured in open fields (Appendix I), birds are easily the most affected animals during hailstorms, and this may affect bird migration. In Mooi River, a hailstorm struck Amur Falcons in March 2019, nesting on trees just weeks before they journeyed back to the Black River of Amur River in Northern China (Sunday Independent, 19 March 2019). Group rescue teams were sent out to collect more than 700 birds that were either killed by the hailstones or needed to be euthanised because of severe injuries. In Howick, in the same month (March 2019), more than 1000 drenched and bruised birds were rescued and taken for rehabilitation where they were fitted with identifying rings and released (Sunday Independent, 19 September 2019). Two weeks after these March 2019 incidents occurred, the Amur Falcons were struck again, in Newcastle; 1000 birds were killed and 840 were sent to rehabilitation centres for identifying rings and to be released (Sunday Independent, 19 September 2019). A reader who wrote to The Mirror (15 April 2015) posed this question: "*Is it possible that birds possess the same survival instinct and somehow knew that a hailstorm was about to strike Pietermaritzburg and migrated to greener pasture, or at least safer pasture?*" This was after the reader noticed the scarcity of birds following a devastating hailstorm the month before (March) but also acknowledged the fact that many of the birds may have been killed.

4.1.1.3 Hail Belts and Swaths

Studying the spatial and temporal variability of hail has proven difficult, from studying hail frequency, size, swaths, and its depth using variable methods (Marcos *et al.,* 2021). Human point observations have underestimated the areal extent of hail damage, hence there has been cross-validation between surface-based reports and radar-derived products (Prein and Holland, 2018). The areal extent of hail damage using radar data is through a decreased vegetation index after a hailstorm event (Gallo *et al.,* 2012).

Hail crop damage described in newspapers has revealed the areal extent of the hailstorm, for example reports would mention: "*zone was scarcely a mile wide*" (Rand Daily Mail, 6 November 1914), "*damage an area 20 miles long and 10 miles wide*" (Rand Daily Mail, 16 November 1931, page 11). Hail areal damage mentioned in the collected newspapers is shown in Table 4.4. These descriptions also reveal the direction in which the hailstorms travelled, which is mostly in a linear fashion; these paths are called hail swaths (Petersen, 1975; Allen *et al.,* 2020). When these paths occur in a specific region, repeatedly, they can form a hail belt (Petersen, 1975). A hail belt can be described as a strip or path where consistent hailfall in concentrated (Petersen, 1975).

Table 4.4: *Areal damage of hailstorm reported in collected newspapers.*

Date	Area of confluence	Areal extent/ description
10 January 1908	Krugersdorp	2-3 miles long by 4-5 yards wide
29 October 1929	Lydenburg	50 morgens of crop ruined
1 February 1936	foothills of Springbok Flats	3-mile belt
1 February 1936	Kalkburt	30 acres of maize destroyed
5 December 1949	Ladysmith	More than 100 acres of young maize destroyed
7 January 1959	Douglas	40 morgens of lucerne destroyed
22 February 1962	Riversdale	10 acres of tomatoes and other crops destroyed
29 October 1969	Brandfort, Tweespruit and Winburg	120 morgens of wheat and 100 morgens of oat field lost
28 January 1972	Brits	38 hectares of wheat of tobacco destroyed
18 December 1972	Bethal	100 square kilometre damage to sunflower seeds and bean harvest
30 October 1977	Delmas	5000 hectares of maize flattened
22 October 1980	Moosrivier	80 hectares of grapes, 800 hectares of citrus trees and 315 hectares of cotton destroyed
5 November 1989	Reitz, Petrus Steyn, Verde, and Warden	9 hectares of wheat destroyed
13 October 1991	Blouputs (Augrabies)	109 hectares of farmland damaged
6 October 1993	Bloemfontein	8000 hectares of wheat destroyed
8 January 1995	Harrismith	400 hectares of maize, 20 hectares of beans, 200 hectares of soya beans and 30 hectares of potato crop destroyed
25 January 2006	Elliot	Storm restricted to 12km radius

An article from the Rand Daily Mail (13 October 1921) explored the idea of hail belts. The writer provides an example of a farm in east Griqualand (Drakensburg foothills) where hail crops would be destroyed each year while the neighbouring farms would go untouched. To 'scientifically' verify this trend; the marks on the trees could be examined due to the hailstones being on the tree branches. However, Dr Innes (in Rand Daily Mail, 30 October 1929, page 15) blatantly states, "*There is no hail belt*"*,* further asking the question: "*Are certain areas more subject than others to destructive hailstorms?*" but finds it hard to answer. He further stated that "*…destructive hailstorms in any given spot are exceedingly rare*"*.* The latter statement goes to show that it does not mean that hail belts are impossible. Dr Innes concludes his argument by stating that "The *law of chances decreases that even rare events may occur twice at the same place, and when destructive storms have been several times experienced on it, a farm is apt to get a bad name."*

Not all studies that research hail belts/swaths explicitly use these terms. Other studies on hail belts are performed through studying hail hotspots, such as Figure 1.1 and other studies discussed in Chapter 1 (p.2). For example, the extensive studies that revealed the Hail Alley; the Hail Alley is the region prone to the highest frequency of hail in North America; it extends from central Alberta in Canada to Texas in the United States of America (USA) (Tolderlund *et al.*, 2021). There are, however, hailstorm events that have occurred in the same place in relatively short space of time, such as for example in Parys (Free State) where there were four major hailstorms on 15 September 2012, 20 October 2012, 9 November 2012 and 6 February 2013 (Bianco, 2013). This scenario repeated in Parys with four hailstorms between November and December 2014 – 1 November 2014, 10 November 2014, 26 November 2014 and 31 December 2014 (Bianco, 2015). Another scenario similar to that of Parys occurred in Ceres, Western Cape, also with four events – 9 November 2013, 15 November, January 2014, and a fourth event which was not dated (Biller, 2014). A farmer in the area reported the hailstorms in Ceres and their account illustrates the concept of hail streak with the statement: "*Fortunately, we've had minimal damage. Our neighbours have not been so lucky."* (Biller, 2014). Púčik (2023) reports on all major hailstorms in 2022, mentioning the dates and locations the events. The dates and locations revealed similar scenarios mentioned above, whereby major hailstorms events are closely dated over certain area.

Hailstorm belts have since been studied and there have been attempts to map them through the use of radar products (Schaefer *et al.,* 2004; Prabhakar *et al.,* 2019). The extent of hail damage caused by hail to vegetation is now largely being studied through remote sensing techniques and geographic information systems (GIS). The Normalised Difference Vegetation Index (NDVI) and Landsat are most accurate; also evident in the studies mentioned in p.71, highlighting studies that used both fruit and crops to research hail damage (Singh *et al.,* 2017). The traditional methods for hail damage detection needs labour intensive field surveys which are time consuming with high costs (Peters *et al.,* 2000). This is especially true for mapping the extent of hail through property, which is normally mapped through insurance reports. With property damage, there has to be site visits to confirm whether the damage was hail caused damage. Hail swaths are also studies with these techniques and validated through surface observations as there have been mismatches between the radar-based hail swaths and ground observations (Ortega *et al.,* 2006; Gallo *et al.,* 2012; Brook *et al.,* 2021).

Hail swath studies withing the Hail Alley have been studied over the Corn Belt as it exposes the hail streaks more prominently (Burks *et al.,* 2013; Bell, 2015; Bell and Molthan, 2016). This type of mapping aids the decisions pertaining to which locations to avoid certain crops (Steyn, 2020); an example of this, from a collected newspaper article was from the Sunday Times (Keeton, 2011), where the occurrence of hailstorms in KZN (including weather, altitude, and humidity) were not conducive to the vineyards in the KZN Midlands. Another example of this was mentioned in 1901, also stating that grapes are not grown in the Free State because of the hail (The Journal, 24 October 1901): "*Grapes do not grow everywhere, as a friend of mine in the Free State said when although he made £70 one year from a very few vines, they were killed by hail for the next three years."* Tree plantations are also not immune. Pinus radiata plantations are susceptible to diplopia, a fungal disease resulting from hail damage, would have an ideal environment in the Western Cape as it has less hail occurrence (McFarlene, 2014).

Hail streaks and hail swaths can be used interchangeably and can be tracked simultaneously when tracking thunderstorm activity. A number of hailstorms were reported to accompany a succession of thunderstorms that were also characterised by the low pressure (7 November 1907, 19 November 1907, 20 November 1907, 22 July 1909). Not all these hailstorms cause damage. Hail streaks produce thin but long bands of hail damage on the ground surface (Haby n.d.). The narrow hail bands cause hail sizes to differ in relatively close locations, whereby severe hail can fall in one place and relatively small hail a few meters away (Haby n.d.). A hail streak study in the Alpine region showed that hail streak frequency and location is strongly dependent on the synoptic scale weather regimes (Nisi *et al.,* 2018). This study, however, did not use hail swaths and hail streaks interchangeably. Hail swaths represented a collective of hail streaks that can be produced in a single thunderstorm, also defining these as spatially coherent areas with hail on the ground inside a storm path (shown in Figure 4.5). Hail belts are thus explained by the repetition of such weather systems.

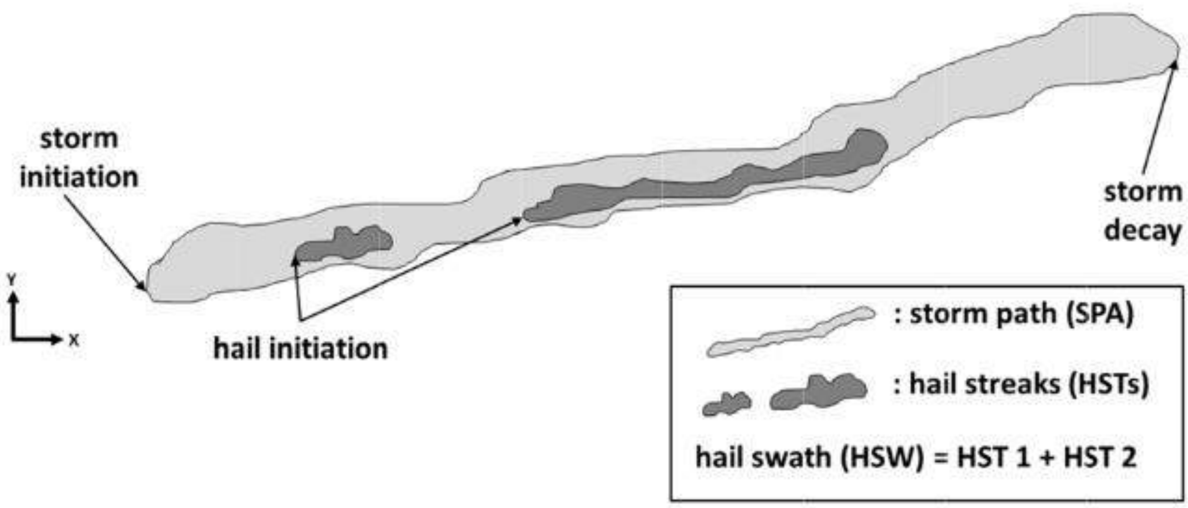


Figure 4.5: *Depiction of the hail streak within a thunderstorm cloud (Nisi et al., 2018).*

4.1.2 Coping and preventative measures

Repeated disasters (weather or non-weather related) in any location leads to developments of coping or preventative measures. This is no different to hailstorm damage. Through newspaper and other forms of hail reporting, it has been evident that a coping or prevention mechanism was established. Farmers and other parties involved in agriculture in hail prone areas would have hail damage as a concern.

4.1.2.1 Hail Nets

To prevent physical damage to crops, farmers implement measures to ensure that there is minimum damage to their harvests. The prevalent solution is the erection of protective nets, especially in orchards and vineyards. This method (illustrated in Figure 4.6a and 4.6b) was used as early as 1928, in an orchard in Kew, Johannesburg. "*The smallest meshed wire-netting is used to make a little roof over each tree… The netting is fixed close to the trees and supporting wires can be raise gradually to the top of the poles as the trees increase in height.*" (Rand Daily Mail, 3 February 1928). Issues with this method are highlighted by Brglez Sever *et al.* (2015), who concluded that the colours of the anti-hail nets can decrease the amount of direct sunlight that reaches fruit and crops and may affect some of their quality parameters. The nets also have the potential to form microclimates which may lead to the development and dynamics of pests and diseases (Brglez Sever *et al.,* 2015; Bosco *et al.,* 2017). However, for those plants that get dried out by the sunlight, hail nets are of great use (Tshisela, 2010).

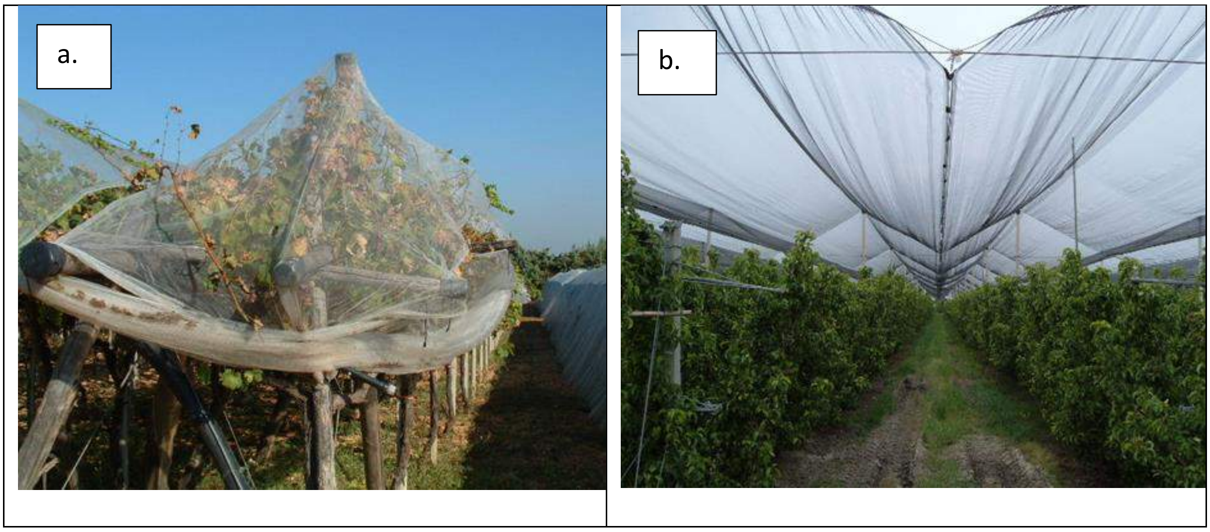


Figure 4.6: *Examples of anti-hail nets structures used in northern Italy. Figure 4.5a shows anti-hail nets set-up in a vineyard. Figure 4.5b shows anti-hail net set-up in an orchard. (Castellano et al., 2008).*

A newspaper article (Feely, 1997) demonstrates the need for anti-hail nets with a report that a company called Alnet's sales of agricultural hail-net orders were much higher than that from the fishing industry. Hail nets have also been used to cover hatchlings in incubators, heated vegetable tunnels, protecting crops from other unwanted damage and as well as cover parking (Blom, 2006; Financial Mail, 30 November 2007; The Witness, 16 April 2010; Ngcobo, 2012). Hail nets are to be installed at an angle that would allow the hail to slide off, this would prevent the weight of the hail to damage the nets (Coetzee, 2011). The effects that hail netting has on crops has been studied on orchards, mainly apples, with the focus on pests (Kührt *et al.,* 2006; Tasin *et al.,* 2008, Baiamonte *et al.,* 2016), lighting and colour (Widmer, 2000; Guerrero *et al.,* 2002; Jakopic *et al.,* 2007; Blanke, 2008; Brglez Sever *et al.,* 2015; Fruk *et al.,* 2016), fertilisation management (Mészáros *et al.,* 2019) and leaves and cuticles (Hunsche *et al.,* 2010). In all studies, the microclimate created by the hail nets created the interest, with findings showing hail nets do not cause significant changes to the apple tree structure. With the growth in use of hail nets around the world, there has also been a growth in the variability or types of hail nets used and farmers would have to choose a suitable hail net for their crops with no requirement on the use thus far (Castellano *et al.,* 2008).The slight change in light transmission to the fruit and the colour of the nets do not create a significant change to the trees. Hail nets also decrease pest infestation (Shahak *et al.,* 2008). Basile *et al*. (2012) studied the effect of colour of hail nets on kiwi fruit, finding the hail net colour has an effect on the parameters of the study at different stages of growth. Further studies on the effects of the colour of the netting on vineyards, ornamental plants and flowers, field crops and fruit trees have been carried out by Shahak *et al.* (2004) with results showing the effects of colour on pests and diseases and the effects of nets on growth and quality of production under these nets (Shahak *et al.,* 2008 and Shahak *et al.,* 2016). The main net colours studied are red, yellow, black, blue, and white.

4.1.2.2 Hail Suppression

Hail suppression or cloud seeding has proven and still proves to be a complicated task, even Munoz (2017) concluded that there is still uncertainty in the quantitative effects and to date, scientific evidence remains inconclusive. This is also proven by Rivera *et al.* (2020) who conclude that after 60 years of hail suppression projects in Mendoza, Argentina - there is still no evidence that hail suppression has any direct consequence to hail frequency and size. In South Africa, these experiments were not well-received by all parties it was believed to benefit.

Before what was termed hail suppression, there were parahails (also known as hail rockets). Parahails were first mentioned in the Rand Daily Mail on 19 February 1913. The apparatus was known to be introduced in France around 1909 to be used as a larger lightning conductor (Rand Daily Mail, 3 December 1952). The parahail apparatus was in the form of a large lightning conductor, that would create electricity from the earth to prevent the formation of hail. By this time, 89 posts were already established in France and were protecting 5615 acres of land, with each tower costing £160 (Rand Daily Mail, 19 February 1913). In 1918, there was another method of hail prevention, by firing a special cannon into the sky (Rand Daily Mail, 22 November 1918). This method was first used in Europe in the 19th century to ensure that the storms stay at a safe distance from their rich harvests (Rand Daily Mail, 30 October 1929). The highly explosive rockets were shot up into the atmosphere to break up the turbulence in the clouds, to prevent the formation of hail (Rand Daily Mail, 30 October 1929).

Both these methods were contested by Mr R.T.A. Innes of the Union Astronomers saying he doubted the real value of the parahail as a preventative measure; hail is formed 6.5km to 8km in the atmosphere and could not see how the firing of cannons could affect its termination. He also did not believe that parahails were of much use. He was in favour of mutual insurance amongst farmers as the best means of covering losses (Rand Daily Mail, 22 November 1918). The question and the idea of how parahails work was further probed in an article of the Rand Daily Mail (30 October 1929), as to what happens to the clouds where parahails are installed – *“Do the clouds move to the neighbours or move to other places in general?”* This problem was also highlighted in the property law which sort out the rights to clouds, air, and precipitation as proof of causation as this was an important question facing plaintiffs (Rabie and Loubser, 1990).

A major rocket industry developed in Italy after World War II, annually sold millions of dollars' worth of explosive rockets to Italian farmers from the 1940's until they were outlawed in the early 1970s (Changnon and Ivens, 1981). The use of these rockets was popular in countries such as China, Kenya, Austria, France, New Zealand, and the Balkan, to name a few (Wieringa and Holleman, 2006). The rockets' main objective is to send shock waves which disturb the atmospheric motions and the intense stillness that preceded hailstorm, this work makes occasional air bubbles in hailstones, turning them into slush or rain (Changnon and Ivens, 1981; Wieringa and Holleman, 2006). The rockets exploded 800 grams of dynamite at 1500 to 2000 meters above ground (Morgan, 2008). Such explosions, however, destroyed hail within a 400-metre radius (Wieringa and Holleman, 2006). Lab experiments would later show that this was insufficient, as one kilogram of TNT hardly affected the hailstones within a 10-meter radius; meaning about 100 000 rockets would be needed to notably affect a single cloud (Wieringa and Holleman, 2006).

Overlapping these rocket experiments to hail, was the use of hail cannons. The hail rockets posed an obvious danger, coming into conflict with civil aviation, subjecting them to serious regulations; the cannons thus became the favoured alternative (Wieringa and Holleman, 2006). These cannons were to send the sound of acetylene explosion, more than 120dB, upward by way of a conical vertical muzzle (Wieringa and Holleman, 2006). Hail cannons were developed by Albert Stinger in 1896, an Austrian winegrower using the theories by Luigi Bombicci from 1880 about wave shock on hail development (Wieringa and Holleman, 2006). As the popularity and the rumours of its success spread into neighbouring countries, over 10 000 cannons were employed in the region around the year 1900. The use became unpopular when the same regions experienced major hail damage. Before this, the failure was blamed in the improper firing of the cannons, as the cannon must be activated before the approach of the storm. Despite the research and inconclusive results from the use of hail cannons well into the mid-20th century, in recent years, a group of industrious companies have revived the cannons, claiming the use of updated technology to prevent hail from falling and saving farmers' crops (Morgan, 2008). There is also a paper by Diepersloot (2012) advocating for return of hail cannons to the agricultural sector, including interviews from farmers who have continuously used hail cannons for over 25 years. Presently, these cannons are produced in Spain, Canada, and Belgium; whilst in other countries such as Italy, France, Austria, Netherlands, United States, Australia, New Zealand, and Tibet, the cannons have been sold unscrupulously to the willing public and farmers (Wieringa and Holleman, 2006).

At this stage of development and continuous research into different anti-hail methods, there were still many questions raised about the existing hail suppression methods and there was much more research to be done about the clouds containing hail. Growers then started to change to silver iodide in the 1950s, known as cloud seeding (Rand Daily Mail, 3 December 1952). South Africa used the on-top method, which dropped silver iodide flares into the top of clouds that are growing at the margins of mature storms (Mather, 1977). Hail prevention studies were still a priority in South Africa well into the 1950s. In the Rand Daily Mail (19 November 1951), a senior lecturer at Stellenbosch University named Dr J.H. Kritszinger, amid uncertainty, said hail clouds are rendered harmless when rockets are fired into them; however, farmers had the attitude that weather should not be meddled with. The farmers' opinions changed after they became convinced that these weather modifications would save them thousands of pounds. Still, at this time, the government needed to be persuaded to fund the parahail towers with most of their motivations being based on the testimonies from France.

In the 1960s, the additional tool to hail prevention was radar data in conjunction with the existing improvements done to hail cannons, shown in Figure 4.6 (Rand Daily Mail, 5 June 1964; Wieringa and Holleman, 2006; Morgan, 2008). Only in 1964 did the Minister of Agricultural Technical Services and Water Affairs, Mr Le Roux, resume the debate of using these two tools to fight hail threatening crops. He motivated his debate by mentioning that Italy, France, Spain, and Swaziland used rockets (cannons) to break up the threatening hailstorms (Rand Daily Mail, 5 June 1964). The governments of the above-mentioned European countries subsidised anti-hail rocket schemes and provided radio information and launching equipment. However, they reported that their results were not entirely conclusive, but farmers were satisfied. The CSIR was approached on the matter but responded they could not consider launching rockets until basic research, costing R3 million, had been carried out.

Mr Le Roux then asked the other Ministers to help launch an anti-hail rocket plan (Rand Daily Mail, 5 June 1964). In Rand Daily Mail (29 April 1972), the debate about weather-modification was brought to parliament with the call for a separate law to control bids to modify weather. The following points were made:

1. The Minister of Water Affairs, Mr P Botha, told the House that injudicious interference with natural falls of rain, hail and snow could lead to a decrease in that rainfall, or increases in hail.
2. Mr Mitchell said the whole question of weather-modification should be dealt with a separate law but welcomed the idea.
3. Weather modification was a field about which very little was known yet as scientists themselves admitted that it involves many factors about which they knew virtually nothing.

The Minister decided the state would control the weather modification programmes and not going to allow individuals to sell rainmaking for commercial gain (Rand Daily Mail, 29 April 1972).

The South African farmers' group in the provinces of Free State, Mpumalanga, Gauteng, and Limpopo used weather modification programmes; although the programmes were initiated in October 1971, much of the progress and implementation occurred in 1972 (Rand Daily Mail, 21 January 1975). The seeding methods ranged from explosive rockets, ground generators to free falling and wing mounted silver iodide flares (Atals, 1977; Federer, 1977). However, Wieringa and Holleman (2006) reviewed the common methods of cloud seeding and concluded that the use of rockets and cannons was a waste of money and effort.

The South African farmers' group collaborated with the Sierra Research Corporation of America (SRCA) to carry out their anti-hail programmes (Rand Daily Mail, 22 January 1972). The tobacco industry's weather modification projects were motivated by the fact that the Lowveld farmers lost up to R400 000 a year in tobacco damage, between 1962 to 1972 (Rand Daily Mail, 27 July 1972). SRCA was not the only company to engage with anti-hail programmes. The Santraoes Co-op of Ficksburg was using another American company, Atmospherics Incorporated, to protect their wheat and other crops from hail in the area within a 110km radius of Bethlehem. Santraoes Co-op also had what was called Santraoes Project Water Hail that had the backing of the Department of Transport and Department of Water Affairs, as the department was interested in increasing the inflow of water into the Vaal Dam. According to Mr Schutte, the programme could cut hail losses by about 50%, while rainfall could be boosted by about 20% (Rand Daily Mail, 27 July 1972). This collaboration was not well received in the Harrismith district; farmers complained that they have had extensive losses to crops and stock since aircrafts started spraying clouds with silver iodide to produce rain (Rand Daily Mail, 24 February 1972). This issue was also to be discussed in the Aberfeldy district of the Free State. One farmer's account: *"I had a terrifying experience a couple of weeks ago when a small cloud drifted across my property. Normally this cloud would not have provided a drop of rain, but there was a devastating hailstorm after a light aircraft flew over the cloud. And it wasn't normal hailstorm either. Huge chunks of ice as big as my fist dropped out of the sky, killing 10 of my sheep instantly and severely injured at least 20 others."* (Rand Daily Mail, 24 February 1972). The research and experimentation continued despite multiple farmers' complaints. According to Atals (1977) titled "*The Paradox of Hail Suppression"*, these farmers may be justified – the silver iodide released by these aircrafts either as a freezing agent (converting water droplets to ice crystals within the cloud) or promoted the growth of crystals from surrounding vapor (creating artificial hail embryos). A hail suppression program based in southern Alberta, Canada traced cloud-seeded storms and found that seeding did increase the mean total rain between 2001 and 2002 (Krauss and Santos, 2004). According to Mather *et al.* (1990), the seeded area in Nelspruit experienced an increase in rainfall 10 to 12 days after seeding has taken place, the reasons for this were inconclusive and the paper's sole purpose was to highlight awareness of the issue. Mather *et al.* (1990) is studied based on evidence from (Bigg and Turton 1986, 1988) who found the rainfall anomaly nine to ten days after cloud seeding took place.

By July 1972, the hail suppression projects were continuing in the Lowveld, where half of South Africa's burley tobacco was grown, due to its promising results (Rand Daily Mail, 27 July 1972). These "promising results" were from research done by the LTK tobacco co-operative on hail suppression projects prior to that in Nelspruit, specifically Project Hailstop which forms part of the Alberta Hail Studies – using the same hail suppression method (Mather, 1977). Mather (1977) provides the detailed processes and experiments done in this particular project. According to the LTK tobacco co-operative in Nelspruit (operating since 21 December 1971), damage to crops dropped by 7% since the weather modification was introduced (Rand Daily Mail, 27 July 1972; Mather, 1977). The average cost of continuing the programme, in collaboration with SRCA, would begin at R406 000 until 1975 and thereafter decrease to R220 000 (Rand Daily Mail, 24 February 1972). The cost of the 6-year programme was estimated at more than R250 000 compared to the hail loss to tobacco crops at R3 458 000 for the same period (Rand Daily Mail, 24 February 1972). However, the LTK co-operative could not finance the programme alone and was investigating the possibilities of getting other agricultural producers – of timber, citrus, and other crops – to take part in the scheme. Farmers in other parts of South Africa were also eager to put their land under the protection of the programmes. At least four big farming areas were negotiating with weather modification to be started in their areas (Rand Daily Mail, 22 November 1972). Following the success in the planning stages, a pilot programme would then follow.

In 1973, the Minister of Water Affairs refused to give a permit to an American company to continue anti-hail operations in Potgietersrus (Rand Daily Mail, 12 November 1973). The Weather Bureau also added that commercial hail prevention should not be undertaken until further research had been done, all the while, the hail-prevention scheme in the Transvaal Lowveld was continuing despite government's opposition. The Rand Daily Mail (24 January 1975) reported that farmers in the Lowveld had started claiming that the Lowveld Tobacco Cooperation was causing the drought in the area by spraying silver iodide to make clouds disperse. A member of the hail prevention steering team reassured the farmers that meteorologists diagnosed the clouds, and that rain is not stopped by the dispersion of clouds, but rather there should be rain instead of hail (Rand Daily Mail, 24 January 1975). In 1977, a 40-minute documentary on weather modification in South Africa by Ernest Christie called "The Storm Fighters" was released, highlighting hailstorm destruction and how hail insurance was paying out (Stainer, 1977).

In 1979, the weather modification programmes in South Africa were back on the defence, with farmers presenting their arguments about the programmes; farmers in the Lowveld voting for the programmes to continue (Norton, 1979). From this year on, there was not much news about the hail suppression in the newspapers, with weather modification schemes focussing mainly on rain augmentation (Matthewman, 1998). The effects on crops and the effectiveness on hail prevention never had a conclusive result, which suggests that it did not yield (sufficiently) positive outcomes. Olivier (1990) has highlighted some of what has been presented in the newspapers; however, these do not give very detailed accounts such as that extracted in newspapers such as that given above. The latest mention of cloud seeding in South Africa has been about a firm in Middelburg, Mpumalanga. However, the use is related to the aid of rainfall rather than hail prevention (Cape Argus, 9 February 2018).

Changnon (1977) provided an update on hail suppression projects done in the Great Plains in USA, mainly concluding that there are mixed reviews and inconclusiveness. Hail suppression concerns highlighted in the paper were also similar to those mentioned in this research around the same time period - in relation to costs and funding, areas of testing and the social and legal ramifications. Other examples of countries with established hail suppression programmes include (but not limited to):

- Greece (Greek National Hail Suppression Program) began in 1984, is reported to still have positive results; cloud seeding has reduced the density of hailfalls and the frequency of large hailstones (Spiridonov *et al.,* 2015; Sioutas, 2017).
- Serbia started hail suppression experiments in the late 1960s - hail suppression may not have a definitive influence and reconsidering its use (Karacostas, 1991; Gavrilov *et al.,* 2013).
- Canada (Alberta Hail Suppression Project), Gilbert *et al.* (2016) concludes that there is belief that the project has influenced the decrease of hail damage.
- China, having had 60 years of weather modification projects, the effects of hail suppression have not been thoroughly evaluated (Ni *et al.,* 2017).

4.1.2.3 Hail Insurance

Through the decreased use and tensions created by the use of weather modification, a widely accepted way for crop protection is through insurance. The earliest known hail insurance can be traced back to 1791 in Germany (Hail Damage Society of Braunschweig) and spread to other European countries in the early nineteenth century (Yoga and Vetrivel, 2012). France hail insurance dates back to 1810 (to be active in the 1820s), Italy in 1830 (the first hail insurance proposal) and the United Kingdom in the 1840s (under the direction of the Farmers and General Insurance Company) (Kneale and Randalls, 2014; Randalls and Kneale, 2020). The USA records hail insurance or crop-hail insurance to only be available to farmers in 1879/80 by Connecticut tobacco growers, with hail insurance on growing crops first underwritten in 1883 (Roth, 1949; Smith *et al.,* 2010). Smith *et al.* (2010) goes on to describe the history and development of hail/crop insurance in the USA. In most countries, hail insurance emerged as a product by and for farming communities and developed into multi-peril insurance (Randalls and Kneale, 2020). Through the newspapers collected for this research, a brief background to hail insurance in South Africa was revealed as follows: this began to appear in the South African newspapers in the 1930s. The first article according to this study’s data was published in the Flemming (1935), about a farmer who insured his crops against hail. It was in this same year that structures have discussions about insurance against hail was published; but these talks soon ended, as the government was not paying attention to the issue (Rand Daily Mail, 13 September 1935). The Pretoria hailstorm of 1949 revived the discussions with Pretoria district heads proposing the 'District Storm Relief Fund' as a way government would intervene in the aftermath of the devastating hailstorm (Rand Daily Mail, 23 December 1949). The funding idea was adopted from the Relief Fund that was set up by the government after a tornado hit Roodepoort in the same year (Rand Daily Mail, 21 November 1949). This was more official than relief funds mentioned in earlier newspapers (Rand Daily Mail, 5 February 1908; Rand Daily Mail, 8 October 1929). The City of Cape Town also followed with a proposal setting up a relief fund in case of any disaster (Rand Daily Mail, 16 May 1950). These funding proposals strengthened the arguments that would be presented to the government about insurance dedicated to hail damage.

These discussions resulted in the creation of the Central Board for Co-operative Insurance, to insure farmers against hail, fire, and other risks (Rand Daily Mail, 22 September 1950). However, hail damage coverage was still not prioritised and thus came at "prohibitive premiums". A counter-solution to that problem was that the Agricultural Co-operative Fire Insurance would be able to give full covers to farmers with hail damage claims. The insurance worked as follows: every member would pay a share of £1 with no further contribution and the conservative estimate for the first year's premiums would be released at £50 000 with negotiable expenses (Rand Daily Mail, 22 September 1950). A farmer wrote to the Rand Daily Mail (24 November 1955, page 5): "*A farmer here cannot insure his fruit against hail damage, but the man in town can insure his house*". This goes to show the mentioned insurance schemes were not successful, as farmers were still left frustrated.

Hail insurance in recent years has been more relied upon. However, it is still expensive and not seen as a priority, causing many farmers to write off their hail damage (Knoetzee, 2013). It remains important that the correct insurance package is chosen, as not all weather-related disasters that may affect agriculture are included in one package. The best suggested insurance is multi-peril crop insurance package as it covers hail, drought, and frost (Kings, 2016; Henderson, 2018). Compared to Burger (1962) the hail insurance history outlined above actually started as general Crop Insurance in 1916 by Western Cape farmers against fire on their wheat crop. Burger (1962) also details the formation on the Central Board for Co-operative Insurance (Sentrakas) was registered under the Co-operative Act in 1950. After its registration, Setrakas and Farmers Hail Insurance secured reinsurance from Santam, cementing crop insurance in South Africa (Marè, 2014). Marè (2014) details of another insurance scheme formed in Ficksburg in 1929, called The Conquered Territory Mutual Hail Insurance Society. The Conquered Territory Mutual Hail Insurance Society was very successful, insuring crops against hail; however, in 1934 it had to be dissolved to make way for a registered co-operative company – presumably how the Central Board for Co-operative Insurance was developed. Sentraal Oes Co-Op was formed in 1970 and saw its first largest claims in 1977 (van Graan, 1977; The Citizen, 14 January 1977; Marè, 2014)

Marè (2014) builds up on the hail insurance research in South Africa by comparing the option of Alternative Risk Transfer (ART), also called Self-Insurance, to Short-Term Crop Hail Insurance. Marè (2014) concludes that both options are viable, however, ART works better for areas in low-medium hail risk whilst Short-Term Crop Hail Insurance is suitable for medium – high hail risk areas. Since hailstorms are localised hazard events, early hail insurance was geographically specific making it easy to become a well-organised form of crop insurance (Yoga and Vetrival, 2012; Kneale and Randalls, 2014). Thus, if a hail insurance covers a wide area, it benefits from the law of large numbers compared to drought and other hazard insurance (Weber, 2019). Hail insurance in South Africa typically covers monetary yield and quality losses as percentages of the agreed insured amount (Steyn 2020). Steyn (2020) further compares the use anti-hail nets with hail insurance from a financial point of view. Anti-hail nets require a long-term investment and also states that they are not economically viable whilst hail insurance is an annual investment (Steyn, 2020). Gandorfer *et al.* (2015) further supports this comparison by highlighting that hail insurance covers monetary yield and quality loss whilst anti-hail nets prevent yield and quality damage.

4.2.1 Damage to property and Infrastructure

Hail damage studies have focussed on agricultural studies, particularly crop-hail damage. Crop-hail damage has been better documented by insurance than property insurance, as the distinction of weather-related types is more prominent on crops (Young and Chandler, 2004). Crop-hail damage has been used to understand the spatial and temporal aspects of economic losses due to hail (Angearu *et al.,* 2021). The lack of economic analysis to hail loss damage is affected by the lack of property-hail loss data (Changnon *et al.,* 2009). Property and infrastructure include people's houses and its contents, business buildings, modes of transport and general public infrastructure. Hailstorm damage to homes and buildings is worsened when accompanied by strong winds and floods, and often leaves people homeless. This may sometimes make it difficult to determine which disaster caused what damage. However, some newspaper damage reports and articles make it possible to distinguish damage caused by hail from that by wind or excessive rain.

The threat to property and infrastructure by hail has increased due to the large property loss as a result of new construction, together with the modern trend of clustering buildings together (Brown *et al.,* 2015). The degree of damage to property also varies, based on factors such as the speed and direction of hail, the size, density and speed of hailstones, the positioning of neighbouring structures and natural barriers and the type and conditioning of the property, materials (Hailstorm Checklist, 2018; Dieling *et al.*, 2020). Figure 4.7 shows the type of property damage caused by hail. Property damage accounts for 22% (445 cases) of the newspaper reported hail damage (Figure 4.2), within this percentage, 37 reports were not very specific, only mentioning that hail did damage to property. 'Other' includes unspecified damage such as furniture, other assets within a particular property, and where 'extensive' or 'considerable' damage was done; accounted for by 229 mentions. Buildings are all structures that were non-residential, accounting for 84 mentions. Houses and homes accounted for by 203 mentions. However, in text, houses and buildings will be used interchangeably.

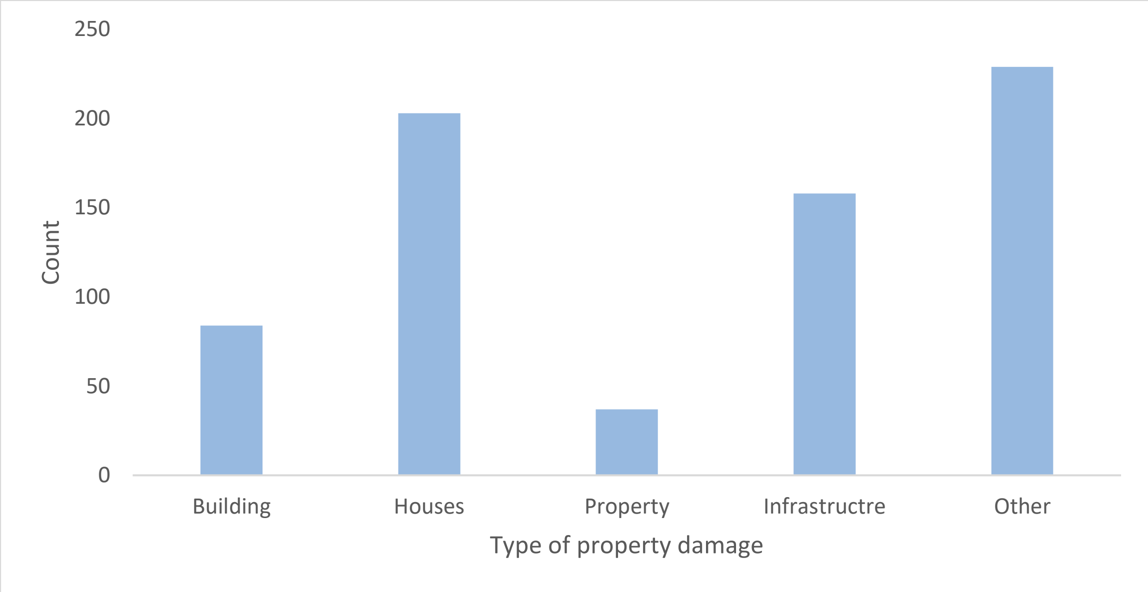


Figure 4.7: *The type of property caused by hail in collected newspaper articles from 1900-2019.*

Hail typically causes damage to the exterior of buildings, which would typically comprise of the most fragile materials, roofs, and windows (Hohl *et al.*, 2002). Broken windows give a chance for rain to enter and cause indoor flooding, further destroying the contents inside. Hail can also cause interior damage, with its ability to penetrate through corrugated iron roofs and tile roofs.

Usually, after hailstones have broken windows or roofs, the holes are covered with plastic tarps because in some cases, the rain may continue for several days after the fact (Rand Daily Mail, 24 February 1972; The Witness, 9 February 2019). This can cause a gap between those with or without insurance. Those with insurance can simply submit a claim and their property damage costs may decrease, "*One telephone call to Absa to resolve their problems was all it took to end the misery…over the past four months since their homes were damaged by hail in November."* (Sowetan, 2 April 2014). Those from rural areas and some townships rely on the government's disaster management and their readiness post-disasters. In 1975, Soweto residents had to repair their own damage or not spend too much money on repairs in case the government would not compensate (Nonyane, 1975).

Hail coupled with very high wind speeds in regions where less resilient material is used, is at higher risk of damage. In many cases, those relying on the government for aid can wait for months or years for the damages to be resolved and may lead to service delivery protests. "*Angry residents from Kagiso on the West Rand have gone on the rampage on Thursday morning, demanding answers from government as to when their houses that were damaged during last year's hail storms will be fixed…"* (The Citizen, 24 October 2014). In rural areas, depending on the fragility of their structures, hailstorms accompanied by very strong winds, have resulted in roofs being blown away and rain with hail falling into the houses (Mthalane, 2015).

Since insurance has not been very inclusive in the terms of all property-hail damage, using radar or satellite products is another option. However, such studies would need lengthy satellite imagery information, as well as standardised methods to identifying material data (Brown *et al.,* 2015). Brown *et al.* (2015) illustrated the difficulty in correlating radar-estimated maximum hailstone size with building damage; the highest severities were not always in correlation with the largest radar derived hail estimates. These discrepancies were a function of building material and the conditions of the materials at the time of the hailstorm (Phillipson *et al.,* 2016).

To identify hail damage to external building material, laboratory testing and field observations are conducted (Marshall *et al.,* 2002). Laboratory tests determine the impact resistance of materials. External damage caused by hail can lead to interior damage through formation of water leaks, insulation gaps and risk to pest intrusion, which can cause expensive problems in the long term (Petty and Monhemius, 2021). Figure 4.8 shows the amount of damage done to the building exterior mentioned in collected newspapers. Windows were the most reported with 239 mentions, followed by roofs with 207 mentions. Gutters are blocked by hailstones and may cause flooding at the top of the building structure (Vista, 24 March 2011; District Mail, 15 May 2012). This can cause flooding in the interior of the house, affecting the ceiling. The ceiling can also be damaged or destroyed by holes made by hailstones on roofs; leaving rain to enter and soak the ceiling structure. This was experienced at a student residency in Parktown, Johannesburg (Mdlankomo, 2012).

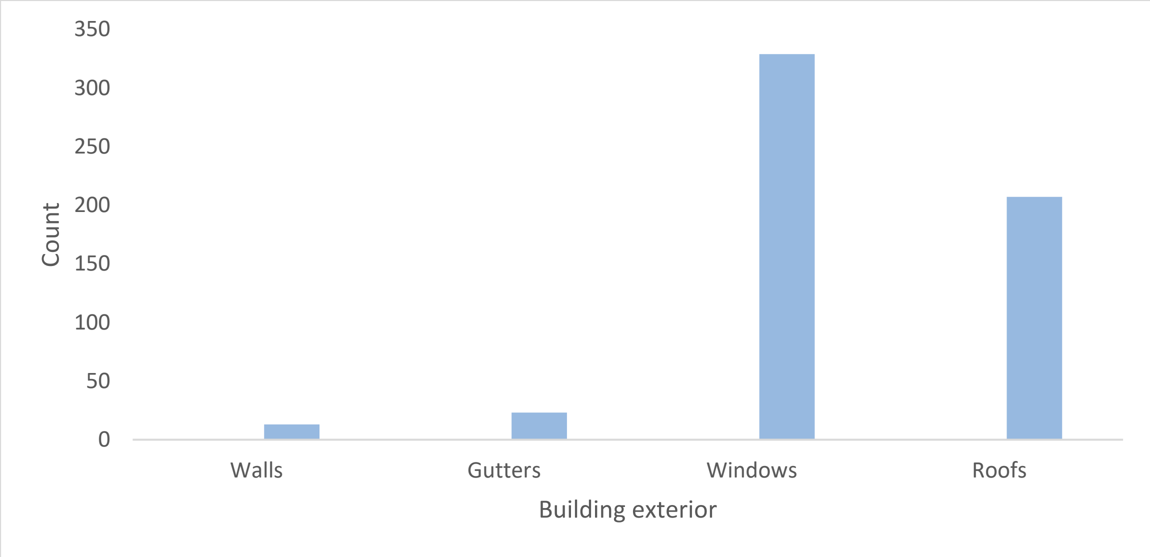


Figure 4.8: *Type of damage done to the exterior of buildings by hail from newspaper reports from 1900-2019.*

The structure of the house can also be affected, depending on the building materials and the country where there is hail occurrence. Different countries have used building material suitable for the climate and region (Khanna *et al.,* 2011). The building structure varies from wood, brick, and glass (Wu, 2015). In South Africa, the dominant building is by brick, with cement (Allen and Crafford, 2016). Hailstones have the ability to mark sandstone houses and cause paint damage by ways of stripping it (The New Age, 9 January 2015).

The variety of building material can bring about fraudulent claims to insurance companies. It thus makes it important to conduct strength tests pertaining to hail. This helps with determining the type of damage hail causes to different building material.

4.2.1.1 Roof damage

Analysis of the consequences from the Appendix I shows hail has caused an issue to roofing for decades, with mentions dating back to 1900. The type of roofs most affected by hail is presented in Figure 4.9. Galvanised or corrugated roofs are the most affected (with 30 mentions), followed by tiled roofs and asbestos. Hailstones having the ability to pierce and dent the materials (Marshall and

Herzog, 1999). Glass roofs and skylights are also affected in the same way. Flat roofs have the ability to hold the hailstones without disposing of them; this can cause interior flooding when the hailstones melt (Rand Daily Mail, 28 October 1927; Rand Daily Mail, 25 November 1936). Hailstones also have the ability to weigh down thatched roofs (Rand Daily Mail, 4 November 1949).

Roofing of any structure serves a purpose to protect and shelter; any damage to it is a formula for an extended loss. Rigby *et al*. (1952) did a study on which roofing materials offer better resistance to hail damage, and Figure 4.10 displays the results of this experiment. The tests were on both local and imported roofing materials used in South Africa. The diameter size of the artificial hailstones used during the tests were a maximum of three inches (76.2mm), causing only dents to the material. Roofing materials that hail has pierced into are corrugated iron, tile, and glass roofs (Figure 4.9).

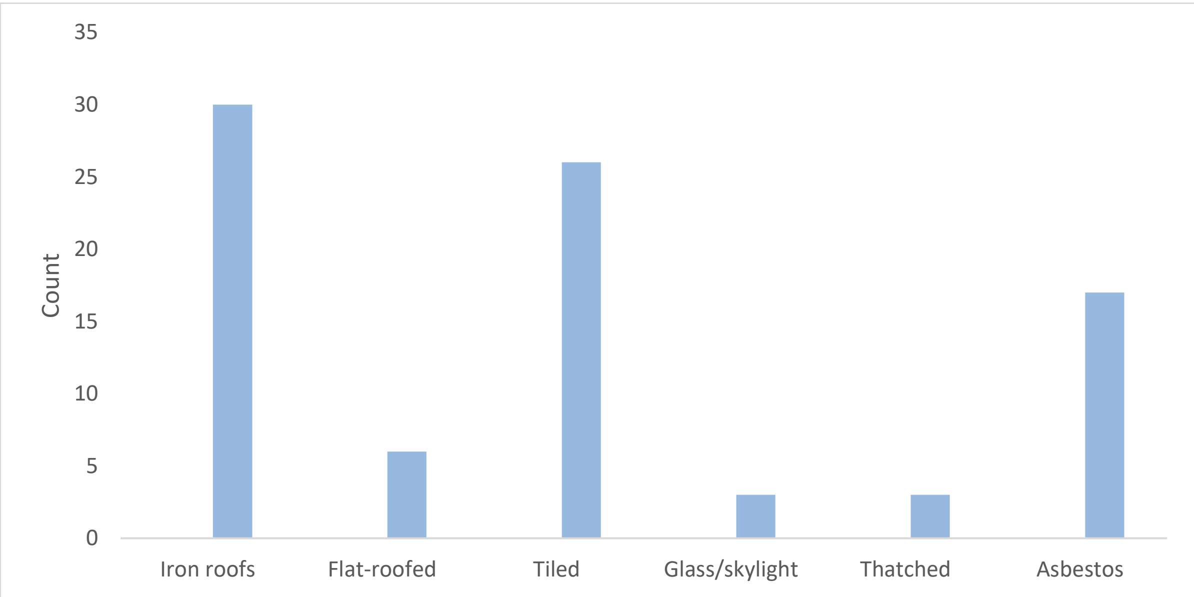


Figure 4.9: *Type of roofing material damaged by hailstones from newspaper reports (1900-2019).*

Wind speed and hailstone sizes are the most contributing factors in the severity of hail damage on roofing (Saini and Shafei, 2019). Similar studies to those by Rigby and Steyn (1952) have been done in recent years, also testing the hail resistance of the roofing materials (Marshall *et al*., 2004; Marshall *et al*., 2010, Saini and Shefai, 2019). Marshall *et al.* (2004) tested the results of hail impacts on numerous types of tile roof materials and found the threshold to average 38mm in diameter. The studies also managed to differentiate between dents and damage from hailstones from other types of conditions. This helps field inspectors when assessing damage following a hailstorm.

The Rand Daily Mail (13 May 1972) stated that corrugated asbestos roofs are mainly to be based at the coast because they have a greater risk of being damaged by hail, and builders have also avoided wood shingle roofs inland because of their low resistance to hail. The corrugated asbestos tiles were already used in inland regions, especially in populated areas more vulnerable to hail damage. This can also be shown in instances where most damaged roofs in big hail events in recent years have been those of corrugated asbestos (Daily Sun, 16 January 2014)

Type	No.	Specimen	Thickness	Roofing details	Impact energy to just cause failure, ft. pdls.	Dia. of Equivalent hailstone** In still air	Dia. of Equivalent hailstone** With wind vel. 60 m.p.h.	Remarks
Corrugated iron	1	Local galvanised 24 gauge	.025"	2" x 3" purlins on edge at 3' 0" o.c. Rafters at 4' 6" o.c.	exceeds 10,000	—	—	These materials were dented only and at impact energies of 2,500 ft. pdls., the dents were shallow. Danger of water damage at the laps due to bending of the sheets was small.
	2	One type of imported galvanised 24 gauge	.025"	As above.	exceeds 10,000	—	—	
	3	24 Gauge metal protected by bitumen and felt on both sides	.11" overall	As above.	exceeds 10,000	—	—	
Slate	4	Slate A, roofed by supplier; slates 9" x 12"	3/8"	1½" x 1½" battens at 4½" o.c. Rafters at 2' 0" o.c.	2,200	2.6	2.3	
	5	Slate A, roofed by Research Officers; slate 9" x 12"	3/8"	1½" x 1½" battens at 4½" o.c. Rafters at 2' 0" o.c.	1,900	2.5	2.2	The values given are those which cracked the slates sufficiently to allow the entry of appreciable rain water. Impact energies 50 to 100% greater were required to punch a hole clean through the slates.
	6	Slate B, roofed by supplier; slate 10" x 18"	3/8"	1½" x 1½" battens at 7½" o.c. Rafters at 2' 0" o.c.	2,100	2.6	2.3	
	7	Slate C, roofed by Research Officers; slates 9" x 12"	3/8"	1½" x 1½" battens at 4½" o.c. Rafters at 2' 0"	1,100	2.2	1.9	
	8	Slate D, roofed by Research Officers; slates 8" x 12"	3/8"—1/2"	1½" x 1½" battens at 5½" o.c. Rafters at 2' 8" o.c.	900	2.1	1.8	
Wood shingles	9	S.A. Pine 1st grade. Size 18" x 7½"	1/16"—9/16"	1½" x 2½" battens at 6" o.c. Rafters at 3' 0"	2,000	2.5	2.2	The values given are those which cracked the shingles. Water damage will probably not be severe at these values. Impact energies about two or three times the limiting values were required to punch right through.
	10	S.A. Cypress 2nd grade. Size 18" x 7½"	1/16"—9/16"	1½" x 2½" battens at 6" o.c. Rafters at 3' 0"	1,700	2.4	2.1	
	11	Canadian Red Cedar 16" x 4" to 7" wide	1/16"—3/8"	1½" x 2" battens at 5½" o.c. Rafters at 3' 0" o.c.	800	2.0	1.7	
Aluminium	12	Plain corrugated 22 gauge	.028"	2" x 3" purlins at 2' 6" o.c. Rafters at 4' 6" o.c.	2,200	2.6	2.3	These materials were more severely damaged near the purlins. Once the material was punctured it was weakened appreciably and subsequent shots easily extended the damage.
	13	Plain, corrugated 24 gauge	.025"	As above.	1,800	2.5	2.2	
	14	Crimped corrugated, 26 gauge	.018"	As above.	1,600	2.4	2.1	
	15	Plain, corrugated, 26 gauge	.018"	As above.	600	1.9	1.6	
Masonite shingles	16	Tempered board 12" x 18" shingles	3/16"	1½" x 1½" battens at 8" o.c. Rafters 2' 6" o.c.	1,800	2.5	2.2	Greatest damage occurred on the under site of the shingles.
	17	Tempered board 12" x 18" shingles	1/8"	As above.	1,200	2.2	1.9	
Corrugated asbestos cement	18	Imported from U.S.A. 4½" pitch	3/8"	2" x 3" purlins on edge at 3' 0" o.c. Rafters at 4' 6"	4,000	3.0	2.7	
	19	Local manufacturer A. Pitch of corrugations 5½" and 7"	1/4"—5/16"	As above.	900	2.1	1.8	Damage was confined to the valleys only.
	20	Local manufacturer B. 5½" and 7" pitch	1/4" 5/16"	As above.	800	2.0	1.7	
	21	Local manufacturer C. 7" pitch	1/4" 5/16"	As above.	700	1.9	1.7	
Clay tiles	22	Marseille type 16" x 8" new	5/8" thinnest	1½" x 1½" battens at 14" o.c. Rafters at 2' 0" o.c.	1,100	2.2	1.9	Both roofs from the same batch of tiles.
	23	Marseille type 16" x 8" after 3 months' exposure	5/8"	As above.	550	1.8	1.6	
Concrete tiles	24	Tile A. Single-lap pantiles 15" x 9"	9/16"—3/4"	1½" x 1½" battens at 11" o.c. Rafters at 2' 0" o.c.	600	1.9	1.6	Pantiles damaged in valleys only.
	25	Tile B. Double interlocking 15" x 9"	9/16"	As above.	550	1.8	1.6	
	26	Tile C. (Imported) double interlocking 16½" x 10"	5/8"	1½" x 2" battens at 14" o.c. Rafters at 2' 0" o.c.	660	1.9	1.7	
	27	Tile D. Double Interlocking 15" x 9"	1/2"	1½" x 1½" battens at 11" o.c. Rafters at 2' 0" o.c.	450	1.7	1.4	
	28	Tile E. Double Interlocking 15" x 9"	9/16"+	As above.	500	1.8	1.5	
	29	Tile F. Brosley 10½" x 6½"	1/2"	1½" x 1½" battens at 4½" o.c. Rafters at 2' 0" o.c.	less than 300	1.5	1.2	

Figure 4.10: *Results from an experiment testing the resistance threshold of different roofing materials (Rigby and Steyn, 1952).*

There was an increase in roofing advertisements in the early 1970s (for example, Figure 4.11 and 4.11b), with the newer roofing companies using hail-proof quality as one of the selling points; because the newspaper was based in Johannesburg, this only made sense due to high hailstorm probability (Rand Daily Mail, 17 November 1973; Rand Daily Mail, 21 January 1974). Metal-based tiles were the leading tiles at the time not only because they were hail-proof but also because they were fungus proof and easy to install (Rand Daily Mail, 11 March 1978). Concrete tiles were not trusted by people, as they did not believe them to be hail-proof, even though tests proved that the hail was not such a problem to them (Rand Daily Mail, 11 March 1978). A company called Roof Tiles contested this costly perception by stating that their tests showed their concrete tiles could withstand 45mm hailstones, up to 20 joules of impact (Rand Daly Mail, 11 March 1978). This quality of concrete tiles as well as improved installation today is what makes it, and clay tiles the most popular in South Africa today (Jekot, 2010).

To reduce the risk of roofs yielding to hailstones, people are encouraged to clear the roofs of the hail as quickly as possible, including the gutter and down pipes as these can cause blockages (Rand Daily Mail, 3 November 1959). Another step taken to decrease the risk is to keep the gutters and down pipes cleared at all times for the same reason (Harper, 2015). Builders have taken it a step further by installing larger gutter boxes and down pipes (Harper, 2015). The function of gutters is to direct rainwater runoff away from a building, this protects the building from excessive and long-term exposure to storm water (Daily Mail, 15 May 2012). There are a variety of gutters, with mainly aluminium, asbestos and PVC in South Africa (District Mail, 15 May 2012). Aluminium gutters are most encouraged in areas with heavy downpours and hail (District Mail, 15 May 2012). The size of the gutter is also dependant on the amount and intensity of rainfall in the area, including the roof drainage area (Zankowski *et al.,* 2013).

Figure 4.11: *Advertisements extracted from the Rand Daly Mail Newspaper. Figure 4.8a shows a roof material advertisement by the company SolaTiles, Figure 4.8b shows a roof material advertisement by the company HarveyTiles. (Rand Daily Mail, 15 October 1973; Rand Daily Mail, 17 November 1973).*

4.2.1.2 Window damage

After a hailstorm event, windows are at high risk of damage, as seen from the results in Figure 4.1. The difference in the types of windows and the evolution of windows is not shown in the newspapers as much as roofing information. However, the history of changes in window glazing is a global issue (Aguilar-Santana *et al.,* 2020). The most common, earliest windows were made from crown glass, and this changed in the 1920s, to plate and sheet glass (Dungworth, 2011). The 1950s saw the introduction of float glass, which is still used today (Janek, 2013). In 2002, a glazing company is South Africa switched from 34 products to more than 1000 products (20 years of Bohle in South Africa, n.d.). The different types of glass are rated for different purposes, such as security, safety, solar control, UV protection, decoration value, building aesthetics, energy efficiency and privacy

(Janek, 2013). Within these, there are also safety glass, which include, soundproof, shatterproof, and bulletproof glass that can be divided into tinted, toughened, and laminated glass (Janek, 2013).

The reporting of windows breaking seems to serve as an indication of hail impact and severity. Hail impact is the result of a combination of hail density and wind speeds and angles (Dieling *et al.,* 2020). The higher the wind speeds, the greater the impact; hail falling at an angle has a higher risk to window damage than a hail fall that is vertical during the fall (Hailstorm Checklist, 2018; Dieling et al., 2020). Broken windows could also reveal the direction in which the hail was falling from, with reports like "*almost all windows facing south, and east were broken*" (Rand Daily Mail, 20 February 1928, page 7) and "*hail broke windows facing the west with force*" (Rand Daily Mail, 22 October 1928) being reported. Hail damage to windows cannot be determined accurately by marks or dents, thus their lifespan and the direction of the hail is used to determine if the damage was due to hailstones (Petty and Monhemius, 2021).

Business would boom for glazier companies after highly damaging hailstorms occurred. Such cases occurred in Mafikeng in the North West province and Johannesburg, Germiston and Springs in the Gauteng province (Appendix 1; Rand Daily Mail, 28 March 1908; Rand Daily Mail, 6 May 1964; Rand Daily Mail, 2 December 1966; Buys, 1983; Rand Daily Mail, 22 November 1984). In these cases, glass in the affected town would run out and must be sourced from businesses in neighbouring towns; some businesses would have month's long waiting lists (Rand Daily Mail, 22 November 1984). In the meantime, residents would have to use makeshift material to keep away bad weather and protect their belongings, most commonly using plastic tarps. There was a case where residents waiting for their window repairs, had to stand guard over their property because it was easier for break-ins to occur in East London, Eastern Cape (East Griqualand Fever, 2017). Window damage has occurred throughout the study period even with changes in the window materials to enhance hail resistance. Such changes have helped to decrease widespread occurrence of hail damage.

The first kind of change introduced was the thickening and multi-layering of the glass instead of single-layered glass (Tuovinen *et al.,* 2018). Other changes include specifying windows with high impact resistance when building and adding silver reflective film to ordinary glass to make it shatterproof (Zuber *et al*., 2013; Hailstorm Checklist, 2018). In areas with high hail occurrence, impact resistance requirements are put into place in the building permit stages, such is the case in Miami-Dade County in Florida, USA (Arasteh *et al*., 2006). Window safety films ensure that glass does not shatter into tiny fragments and enter a home with a force enough to injure occupants (The Institute for Catastrophic Loss Reduction, 2018). Additionally, safety films reduce the risk of water entering through broken windows (Janek, 2013). South Africa has very strict national standards and building regulations that govern the installation of glass in buildings. When buildings are constructed, drawings that presented to show the specifications for the approval by the local authority or municipality that governs the area (Janek, 2013).

4.3.1 Transport Damage

Window damage is not only reserved for buildings but also very problematic when it comes to transportation (Rowan *et al.,* 2013). Figure 4.12 shows the comparison of which mode of transport was most affected, with Figure 4.13 showing the distribution of the mentions from 1900 to 2019. Vehicles record the most mentions with 130 mentions, followed by airplanes with 12 mentions and trains with seven mentions.

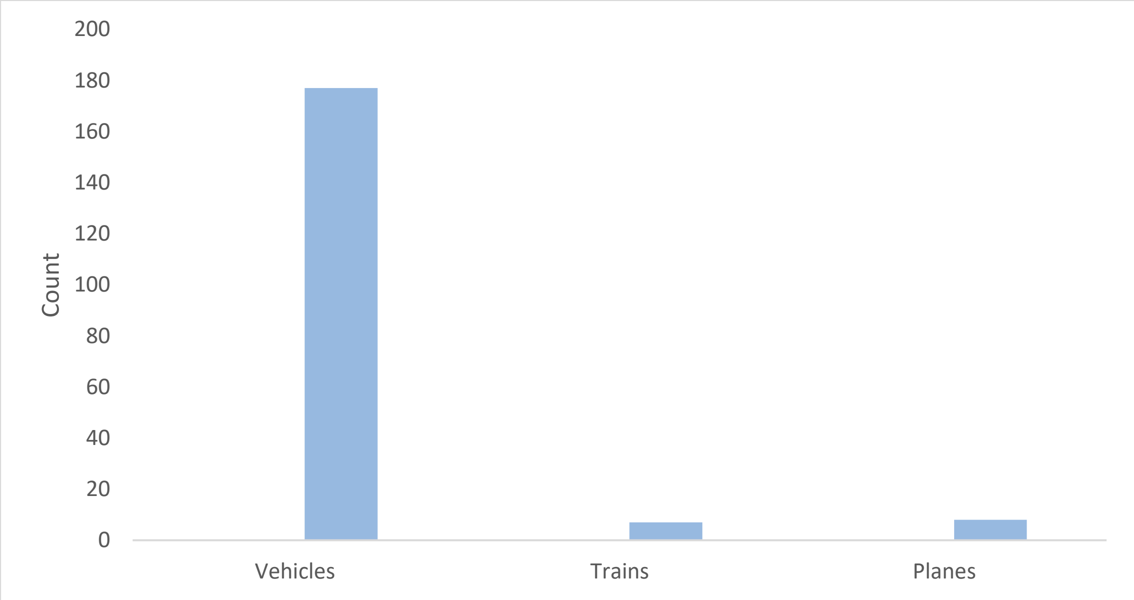


Figure 4.12: *Quantified hail damage of different modes of transport from collected newspaper articles from 1900-2019.*

Mentions of transportation in newspapers is reported sparsely until the 1960s when the mentions are reported yearly from 1968. The last train damage report is in 1940 and first mentioned in 1914. Airplane damage is more randomly reported, with the first mention in 1935. Vehicles are first mentioned in 1928 and make the trend seen in Figure 4.13.

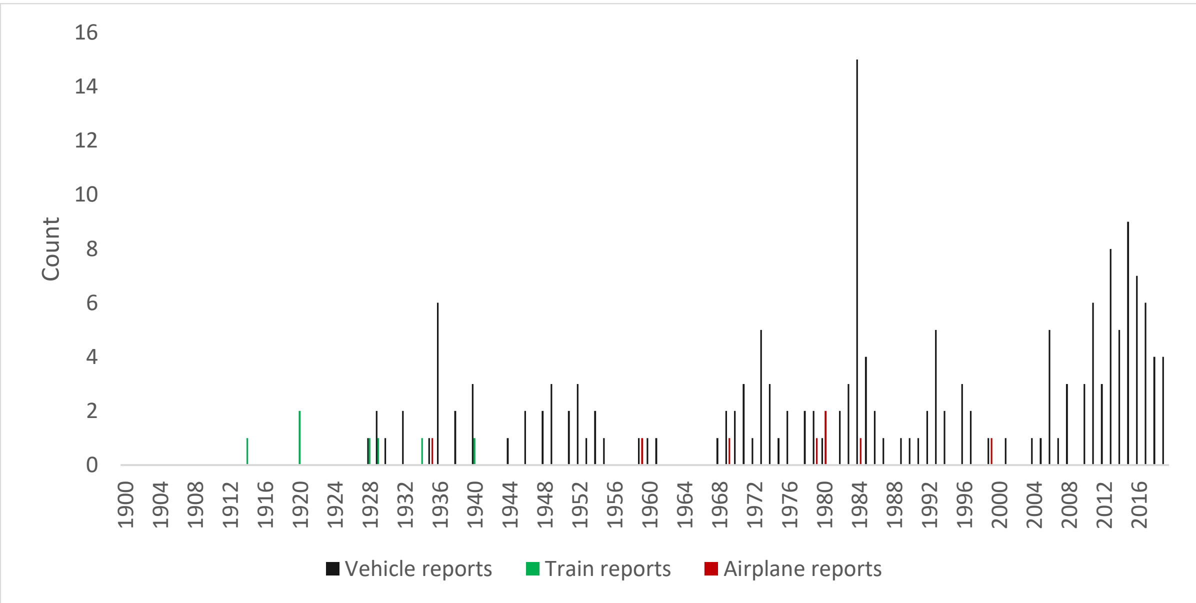


Figure 4.13: *Number of hail damage reports related to vehicles (red), trains (green) and airplanes (purple) from newspaper articles (1900-2019).*

4.3.1.1 Vehicle damage

Typical vehicle damage includes damage to windows, windscreens, and dentation to the bodywork. The first mention of vehicle damage was in Johannesburg (18 October 1928 hailstorm) when its windows, windscreens were broken, and the hailstones entered through the openings, hailstones piled up on the car hood causing severe dents in the process (Rand Daily Mail, 19 October 1928). Damage to vehicles can be expected from hailstones with a diameter larger than 12.7 millimetres. The extent of the damage is mainly influenced by factors that influence that of property mentioned earlier in the chapter, the material and thickness of the bodywork and the construction of the outer panels and accessories (model of the vehicles) will also determine the amount of damage to the vehicle (Hailstorm Checklist, 2018). Hail dents can cause car write offs if the cost of repairs exceeds 60% (Hail Free Solutions, 2021).

Hail damage to vehicles is made severe if the vehicles are not under any protective shelter or the hailstorm takes place during hours when there is traffic. "*Kilfoil said this additional parking space was not covered and the 1500 cars had been badly damaged by hail last week"* (Cokayne, 2013); "*I was stationary in the hail for almost 10 minutes. I have visible dents all over my bonnet and roof, and two large cracks on my windscreen…and she'd had no choice but to sit in traffic and listen to the hail beat down on the car."* (Pieterse, 2015). The number of vehicle damage claims post-hailstorm can also highlight the severity of hail damage to a vehicle: "*A Pietermaritzburg vehicle body repair company has gone to the extent of bringing in 20 expert Brazilian technicians to cope with the influx of customers after Friday's hail storm. Bevan Clayton, owner of Hail Busters in Boom Street, said yesterday they had handed out almost 300 quotations for repairs to damaged vehicles over the weekend"* (Umraw, 2015, page 3).

Insurance companies have also been sending out hail-warnings to their clients to allow them time to shelter and protect their vehicles and reduce repair costs (Dyson, 2016). The warnings that are sent out by the insurance companies and other parties who would benefit from it are dependent on the radar and hail-warnings issued by the SAWS (Stent, 2006; Dyson, 2016). However, it is also very important for motorists to check whether their insurance policies cover hail (Stanger Weekly, 11 July 2018).

4.3.1.2 Airplane damage

The Rand Daily Mail (15 October 1979) reported an Air Force plane made a melon patch landing as its windows, lights and part of the tail were damaged due to a violent hailstorm which also caused reduced visibility. One of the pilots had facial bruises from the hailstones coming through the broken windows. The Rand Daily Mail (15 January 1980) also reported airplanes suffered wing damage and 15 Boeing airplanes at the Jan Smuts Airport (now known as OR Tambo International Airport) were damaged. This hailstorm caused many flights to be delayed and left many passengers stranded. South African Airways had to fly in technicians and spare parts as they were struggling with the repairs, also redirecting incoming flights to Lanseria Airport. There are no other reports of flight delays due to hailstorms, but rather, due to severe thunderstorms in the area.

Other examples of airplane hail damage include a nose section of an aircraft being detached from the body and the wind shield of the cockpit cracked due to an impact of a hailstone in Gimpo Airport, Korea, 9 June 2006 (Korea Aviation and Railway Accident Investigation Board, 2008). Another incident was reported in Geneva when an airplane flew into a hailstorm cell and cracked the windshield; the oxygen in the plane was compromised with damage found on the leading edges of the wings and tails, engine nacelles, windshield, and redome, forcing a landing just 14 minutes after the impact (Lacagnina, 2007). Through these incidents, it has been important for resistance of the glass fibre laminates used on planes (Jayababu *et al*., 2020).

Field *et al.* (2010) reviewed how hail threats are considered in existing regulatory frameworks as well identifying the requirements for hail resistance and environments in manufacturing. Urdiroz (2017) points out that there is no civil aircraft structure that is built to absorb the impact of a large hailstone without damage. Damage to the airplane structure is of most concern during a flight, where the interaction of the speed of the airplane and hailstone (and size) may be at their maximum (Neidigk *et al.,* 2017). It is therefore important for other methods of safety to be implemented. Implementation of other safety methods are of importance.

One of the most effective ways is avoiding the areas of hailstorms during the flight, through continuously enhancing weather radar systems (Sauer *et al*. 2019). The whole airplane structure is at risk of hail damage. Discussions about simulations to assess hail impact damage to different parts of the show damage to fin, tailplane, flaps, tail surfaces, engine cowls, radome, ailerons, and spoilers airplane (Field *et al*., 2010; Neidigk et al., 2017; Goraj and Kustron, 2018). Investigators of an aircraft crash in the Drakensburg, where 11 people died, and suspected hail caused the deterioration of the aircraft, leading it to crash (Loewe, 2012a). The fabric covered rudder, elevator and aileron were shredded, typical of hail damage, the metal fuselage and other parts of the plane were going to be checked for hail impact dents. Unfortunately, an article detailing the outcome of the investigation could not be found (Loewe, 2012b).

4.4.1 Human injuries and fatalities

Human injuries and fatalities have a range of causes during hailstorms, but this kind of damage is not very common, as seen in Figure 4.1. Newspaper articles have detailed many accounts about hailstone impact damage to people (Figure 4.14). Direct injuries include hailstones bruising bodies and some people being knocked unconscious, these are made severe when the hailstones are carried by strong winds (Rand Daily Mail, 3 February 1936; Rand Daily Mail, 14 October 1948; Machakela and Petersen, 2008). Most injuries and deaths are indirect and are in line with the cause and effect of stormy weather.

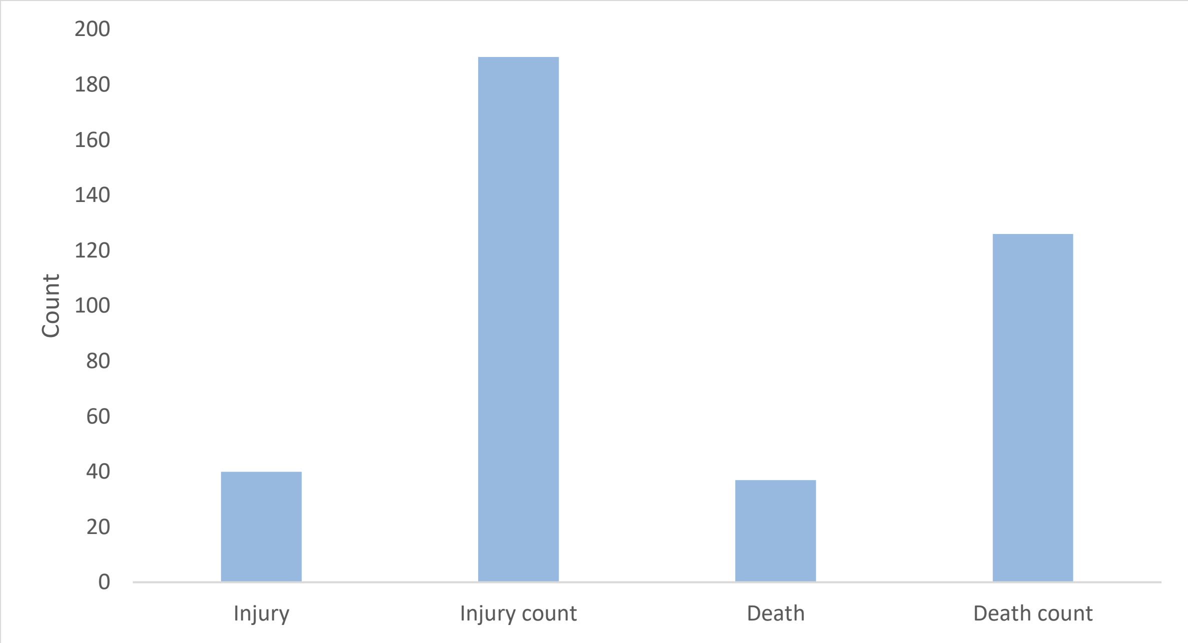


Figure 4.14: *Count of injury and death, together with the number of people affected by hail from newspaper reports from 1900-2019.*

There are 40 mentions of injuries and 37 mentions of death because of hailstones or hailstorm in collected newspapers. The injury count was much higher than the death count (190 versus 126 people). Examples of indirect injuries and deaths include cuts from flying glass from windows breaking, roofs and walls collapsing due to structure failure caused during the hailstorm, vehicle accidents cause by icy slippery roads, reduced visibility, and windshield damage (Machakela and Petersen, 2008; Diamond Fever Advertiser, 5 February 2016; Mnisi, 2018). Besides building stronger and more weather resistant building structures, it is important for people to immediately look for shelter during a hailstorm as the hailstones may even get bigger with time and to keep the curtains or blinds closed to protect them from flying glass (Hail Checklist, 2018).

5. CONCLUSION

The research aimed to establish the geographical and historic occurrence of destructive hail events and hailstorms in South Africa over the last 119 years; this has exposed the nature of consequences and human responses to such events. This was accomplished through the use newspaper articles which reported severe hailstorm events. In recent times, satellite-based techniques have also contributed to the development of new methods for hail mapping, including the use of both geostationary and polar orbiting satellite data (Rivolta *et al.,* 2010). New methods developed from using satellite-based techniques include creating models and using these to develop forecasting techniques and researching components that cause hail formation (Schulze *et al*., 2004).

The results and discussion of the research's objectives are confined to Chapter 3 and 4. A map of the areal coverage of destructive hail/hailstorms in South Africa based on reported newspaper articles are presented in Chapter 3, together with the spatial and temporal patterns of the hail events. The potential changes in the nature of destructive hailstorms were also explored, through examining the annual changes in hail events nationally and provincially. The associated consequences of these identified hail events to agriculture, infrastructure, transport, and human lives are quantified and presented in Chapter 4.

A summary of these two chapters and their important findings are listed below, guided by the objectives of the dissertation.

Objective 1*: Determine and map the areal coverage of destructive hail//hailstorms*

Through mapping the newspaper reported hail events, the central and eastern parts of South Africa are seen to have majority of the hail events. The areal coverage for each province was analysed, including the changes which were studied through a 60-year period difference. The findings were affected by the number of newspaper reports; however, the general spatial patterns could be observed. The observed changes in the provinces were due to a number of reasons, such as population migration or urbanisation, newspaper reports and publication in each province, altitude, and the dominant weather systems in different regions that would support the development of hail activity. The nature in which hail falls and the variable weather-related circumstance in the country leads to contrasting hailstorm/hail occurrence statistics from one province to another, and even within given provincial regions.

Objective 2: *Determine the temporal patterns of destructive hail/hailstorms*

Seasonal hail patterns showed majority of the hailstorms occurring the austral summer (October to March), with occurrences peaking in November. There is an increase in hail events April, and through analysis of weather types and conditions, showed an increased in hail-conducing weather activity (namely strong winds, thunderstorms, torrential rains, and lightning). This additional weather activity causes increased hail days in the month of September. The seasonal analysis for each province showed the following months as having the most hail events:

- **Limpopo:** November, October, January, December/March
- **North West, Gauteng, and Mpumalanga**: November, October, December and January.
- **KZN**: December, January, November and October
- **Eastern Cape**: January, December, November and October
- **Free State**: November, December, October and January
- **Northern Cape**: November, October, April and January
- **Western Cape**: November, December, October and march/June.

The diurnal analysis was conducted by dividing the times into morning (06:00-12:00), afternoon (14:00-18:00), evening/night (18:00-00:00) and early morning (00:00-06:00). Findings show that 55% hail events occur in the afternoon, between 15:00 and 18:00. Further analysis into monthly diurnal patterns, shows June and July experiences evening/night hail events compared to other months and an absence of late afternoon hail events. Provincial diurnal patterns show all provinces experience afternoon rainfall, except Limpopo which mostly receives evening/ night hail events.

Objective 3: *Identify any potential changes in the nature (severity, frequency) of destructive hailstorms.*

Hail/hailstorms are made severe by accompanying high wind speeds and the size of hailstones. Only (31%) of newspaper articles reported wind speeds, therefore, wind speeds were determined by descriptions such as cyclone, hurricane, and gale force winds. Hailstones had a variety of descriptions, which were standardised through hailstone measurements in Bal *et al.* (2014). The changes in severity of hailstorms through wind speeds and hailstone analysis were not possible as the newspaper articles did not always mention the two parameters together. The severity was thus studied through hail damage – which is highly dependent on general exposure of either crops or property. Thus, this route is inconclusive.

The frequency change and calculation are dependent on number of newspaper reports. However, the last 60 years saw a decline in the overall newspaper reports (and number of hail days) despite the increase in newspaper publishers. However, within the last 60 years, there was a notable increase in hail days and newspaper reported hail events from 2005, with a peak in 2013. Different weather and climate patterns were explored including ENSO cycles to determine whether they had any influence on hail frequency. The years correlating with La Niña phases had a greater number of hail days than El Niño phases.

Objective 4: *Associate the characteristics of destructive hail/hailstorms with their consequences.*

Hail damage to agriculture, property and infrastructure were affected by wind speeds during a hailstorm, the angle in which hailstones make impact and the weight of individual hailstones. Identified coping and prevention methods for crop-hail damage are hail nets, hail suppression methods using hail cannons and spraying silver iodide into thunderstorm clouds to prevent the development of hailstones and monetary compensation through insurance and government assistance. Hail damage to property and infrastructure is determined to mainly be external and with internal damage caused by the failure of external structures. Affected modes of transport include vehicles, trains, and aeroplanes; also experiencing damage externally. Hail damage to human lives is both direct and indirect, with reports of head injuries and deaths caused indirectly by accompanying weather conditions.

Objective 5: *Interrogate the narrative framework journalists use when reporting hail/hailstorms.*

Newspaper articles have proven to contain very detailed information of destructive hail/hailstorm occurrence and their consequences. The newspaper articles reported details on the formation of hail, hailstorm damage to different stakeholders as well as spatial and temporal occurrence of hail. The articles served to inform the public about the hail events, including the developments of the coping and preventative mechanisms with regards to hail/hailstorms. The Rand Daily Mail newspaper provided (65%) of the articles used for this research, with their reports giving great details on the hail events. Recent newspapers have focussed more on the social and financial implications of hail. A growth in newspaper publications has allowed for the repetitive reporting a single hail events, with financial and business focussed newspapers emphasising the cost of damage. The most reported coping measure for hail has focussed on vehicles and households, encouraging people to rely on insurance.

Climate and weather-related events, with emphasis on global warming and climate change have received attention in recent years. Newspaper articles can be used to study these subjects including social responses to related to them.

6. REFERENCES

Admirat, P., Goyer, G.G., Wojtiw, L., Carte, E.A., Roos, D. and Lozowki, E.P. 1985. A Comparative Study of Hailstorms in Switzerland, Canada and South Africa. *Journal of Climatology*, 5(1), pp.35-51.

Akhmedovic, I.S., 2014. The Mechanism of Hail Formation and a Method to Prevent it. Physical *Chemistry*, 4(2), pp.21-29.

Allan, R., Endfield, G., Damodaran, V., Adamson, G., Hannaford, M., Carroll, F., Macdonald, N., Groom, N., Jones, J., Williamson, F. and Hendy, E. 2016. Toward Integrated Historical Climate Research: The Example of Atmospheric Circulation Reconstructions Over the Earth. *Wiley Interdisciplinary Reviews: Climate Change, 7(2), pp.164-174.*

Allen, J.T., Tippett, M.K. and Sobel, A.H., 2015. Influence of the El Niño/Southern Oscillation on Tornado and Hail Frequency in the United States. *Nature Geoscience*, 8(4), pp.278-283.

Allen, J.T. and Allen, E.R. 2016. A Review of Severe Thunderstorms in Australia. *Atmospheric Research*, 178, pp.347-366.

Allen, C. and Crafford, K., 2016. African Energy-Plus Construction—A Case Study of House Rhino. In: *Sustainable Ecological Engineering Design, Springer, Cham*, pp.95-109.

Allen, J.T., Tippett, M.K. and Sobel, A.H. 2015. An Empirical Model Relating US Monthly Hail Occurrence to Large-Scale Meteorological Environment. *Journal of Advances in Modeling Earth Systems*, 7(1), pp.226-243.

Allen, J. T., Giammanco, I. M., Kumjian, M. R., Punge, H. J., Zhang, Q., Groenemeijer, P. 2020. Understanding Hail in the Earth System. *Reviews of Geophysics*, 58, Article e2019RG000665. Available from: https://doi.org/10.1029/2019RG000665 [accessed 20 April 2022]

Alexander, M. 2018. The Provinces and Homelands of South Africa Before 1996. *South Africa Gateway* [online]. Available from: https://southafrica-info.com/infographics/provinces-homelands-south-africa-1996/ [accessed 4 March 2023].

Ali, F.M. 2014. Analysis Of Role of Media in Disaster Reporting in Pakistan. In: *1st Mediterranean Interdisciplinary Forum on Social Sciences and Humanities*. *MIFS 2014*, 2, pp.598-603.

Angearu, C.V., Ontel, I., Irimescu, A. and Sorin, B. 2021. Assessment of the Hail Damage on Agricultural Crops from North of Baragan Plain, Romania, Using Remote Sensing Data. *Research Square* [online], pp.1-23. Available from: https://doi.org/10.21203/rs.3.rs-1180239/v1 [accessed 22 July 2022].

Aguilar-Santana, J.L., Jarimi, H., Velasco-Carrasco, M. and Riffat, S. 2020. Review on Window-Glazing Technologies and Future Prospects. *International Journal of Low-Carbon Technologies*, 15(1), pp.112-120.

Arasteh, D., Selkowitz, S., Apte, J. and LaFrance, M. 2006. Zero Energy Windows (No. LBNL-60049). Lawrence Berkeley National Lab (LBNL), Berkeley, CA (United States).

Athanasis, N., Themistocleous, M., Kalabokidis, K., Papakonstantinou, A., Soulakellis, N. and Palaiologou, P. 2018. The Emergence of Social Media for Natural Disasters Management: A Big Data Perspective. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-3/W4, pp.75–82. Available from: https://doi.org/10.5194/isprs-archives-XLII-3-W4-75-2018 [accessed 22 July 2022].

Atals, D. 1977. The Paradox of Hail Suppression: Under Different Circumstances, Cloud Seeding May Result in Either Increased or Decreased Hail. *Science*, 195(4274), pp.139-145.

Baggett, C.F., Nardi, K.M., Childs, S.J., Zito, S.N., Barnes, E.A. and Maloney, E.D. 2018. Skillful Subseasonal Forecasts of Weekly Tornado and Hail Activity Using the Madden-Julian Oscillation. *Journal of Geophysical Research: Atmospheres,* 123(22), pp.12-661.

Baiamonte, I., Raffo, A., Nardo, N., Moneta, E., Peparaio, M., D'Aloise, A., Kelderer, M., Casera, C. and Paoletti, F. 2016. Effect Of the Use of Anti-Hail Nets on Codling Moth (Cydia Pomonella) And Organoleptic Quality of Apple (Cv. Braeburn) Grown in Alto Adige Region (Northern Italy). *Journal of the Science of Food and Agriculture*, 96(6), pp.2025-2032.

Baker, A.R. 2012. Hail as Hazard: Changing Attitudes to Crop Protection Against Hail Damage in France, 1815–1914. *Agricultural History Review*, 60(1), pp.19-36.

Bal, S.K., Saha, S., Fand, B.B., Singh, N.P., Rane, J. and Minhas, P.S. 2014. Hailstorms: Causes, Damage and Post-Hail Management in Agriculture. *Technical Bulletin*, 5, pp.1-44.

Barnes, M.D., Hanson, C.L., Novilla, L.M., Meacham, A.T., McIntyre, E. and Erickson, B.C. 2008. Analysis of Media Agenda Setting During and After Hurricane Katrina: Implications for Emergency Preparedness, Disaster Response, And Disaster Policy. *American Journal of Public Health*, 98(4), 604-610.

Barrett, A.I. and Hoose, C. 2022. Microphysical Pathways Active within Thunderstorms and Their Sensitivity to CCN Concentration and Wind Shear. *Journal of Geophysical Research: Atmospheres*, 128, Article p.e2022JD036965. Available from: https://doi.org/10.1029/2022JD036965 [accessed 6 June 2022]

Basara, J.B., Cheresnick, D.R., Mitchell, D. and Illston, B.G., 2007. An Analysis of Severe Hail Swaths in the Southern Plains of the United States. *Transactions in GIS*, 11(4), pp.531-554.

Basile, B., Giaccone, M., Cirillo, C., Ritieni, A., Graziani, G., Shahak, Y. and Forlani, M. 2012. Photo-Selective Hail Nets Affect Fruit Size and Quality in Hayward Kiwifruit. *Scientia Horticulturae*, 141, pp.91-97.

Bednarczyk, C. and Sousounis, P., 2012. Hail Climatology of Australia Based on Lightning and Reanalysis. Available at https://ams.confex.com/ams/27SLS/webprogram/Manuscript/Paper255889/extendedAbstract_pdf.pdf [accessed 2 February 2022]

Begley, P. 2005. The El Niño-Southern Oscillation, Rainfall and Wheat Yields in South Africa (Master's Thesis, University of Cape Town).

Behera, S.K. and Yamagata, T. 2001. Subtropical SST Dipole Events in the Southern Indian Ocean. *Geophysical Research Letters*, 28(2), pp.327-330.

Bell, P. 1984. ‘Hundreds of Houses Still Waiting for Repairs’, *Rand Daily Mail,* 20 December, pp.6.

Bell, J. R., and A. L. Molthan, 2016: Evaluation of Approaches to Identifying Hail Damage to Crop Vegetation Using Satellite Imagery. *Journal of Operational Meteorology*, 4 (11), pp.142-159.

Berthet, C., Dessens, J. and Sánchez, J.L. 2011. Regional and Yearly Variations of Hail Frequency and Intensity in France. *Atmospheric Research,* 100(4), pp.391-400.

Bianco, J. 2013. ‘Summer Hail and Heat’, *Parys Gazzette,* 21 February, pp.9.

Bianco, J. 2015. ‘Summer of Suffering’, *Beeld*, 2 March, pp.6.

Bihon, W., Slippers, B., Burgess, T., Wingfield, M.J. and Wingfield, B.D. 2012. Diverse Sources of Infection and Cryptic Recombination Revealed in South African *Diplodia Pinea* Populations. *Fungal Biology*, 116(1), pp.112-120.

Biller, H. 2014. ‘Main Course. Orchard Okes’, *Sunday Times*, 2 Febraury.

Blair, S. F., and Leighton, J.W. 2012. Creating High-Resolution Hail Datasets using Social Media and Post-Storm Ground Surveys. *Electronic Journal Operational Meteorology*, 13 (3), pp.32-45.

Blamey, R.C., Middleton, C., Lennard, C. and Reason, C.J.C. 2017. A Climatology of Potential Severe Convective Environments Across South Africa. *Climate Dynamics*, 49(5), pp.2161-2178.

Blanke, M.M. 2008. The Structure of Coloured Hail Nets Affects Light Transmission, Light Spectrum, Phytochrome and Apple Fruit Colouration. *International Symposium on Horticulture in Europe*, 817, pp. 177-184.

Blom, N. 2006. ‘Crocodiles a Snap for Entrepeneur’, *Business Day,* 4 December.

Bosco, L.C., Bergamaschi, H., Cardoso, L.S., Paula, V.A.D., Marodin, G.A.B. and Brauner, P.C. 2017. Microclimate Alterations Caused by Agricultural Hail Net Coverage and Effects on Apple Tree Yield in Subtropical Climate of Southern Brazil. *Bragantia*, 77, pp.181-192.

Botzen, W.J.W., Bouwer, L.M. and Van den Bergh, J.C.J.M. 2010. Climate Change and Hailstorm Damage: Empirical Evidence and Implications for Agriculture and Insurance. *Resource and Energy Economics*, 32(3), 341-362.

Brglez Sever, M., Tojnko, S. and Unuk, T. 2015. Impact Of Various Types of Anti-Hail Nets on Light Exposure in Orchards and Quality Parameters of Apples-A Review. *Agricultura (Slovenia),* 12(1/2), pp.25-31.

Brook, J.P., Protat, A., Soderholm, J., Carlin, J.T., McGowan, H. and Warren, R.A. 2021. Hailtrack—Improving Radar-Based Hailfall Estimates by Modelling Hail Trajectories. *Journal of Applied Meteorology and Climatology,* 60(3), pp.237-254.

Brown, T.M., Pogorzelski, W.H. and Giammanco, I.M. 2015. Evaluating Hail Damage Using Property Insurance Claims Data. *Weather, Climate, and Society*, 7(3), pp.197-210.

Bruick, Z.S., 2019. Characteristics of Hailstorms and ENSO-Induced Extreme Storm Variability in Subtropical South America (Doctoral Dissertation, Colorado State University).

Bruwer, A., van Staden, M., Le Roux, A. and van Niekerk, W. 2017. Disaster Management and Risk Reduction in South Africa. *South African Risk and Vulnerability Atlas: Understanding the Social & Environmental Implications of Global Change*, pp.105-111.

Buckley, B.W., Sullivan, W., Chan, P. and Leplastrier, M. 2010. Two Record Breaking Australian Hail Storms: Storm Environments, Damage Characteristics and Rarity. In: 25th Conference on Severe Local Storms, *American Meteorological Society*, Colorado, pp.11-14.

Burger, O.E. 1962. All-Risk Crop Insurance. *Agrekon,* 1(3), pp.31-39.

Business Day. 17 October 1997. El Nino.

Butgereit, L. 2014. Tracking Gauteng Thunderstorms Using Crowdsourced Twitter Data Between Soweto and Pretoria. *TD: The Journal for Transdisciplinary Research in Southern Africa*, 10(3), pp.293-309.

Buys, J. 1983. ‘. Hundreds of Houses Still Waiting for Repairs’, *Rand Daily Mail,* 5 November, pp.6.

Campbell, B.M., Vermeulen, S.J., Aggarwal, P.K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A.M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., Thornton, P.K. and Wollenberg, E. 2016. Reducing Risks to Food Security from Climate Change. *Global Food Security*, 11, pp.34-43.

Cape Argus. 9 February 2018. Sowing seeds to bring about much-needed rain. Page 9.

Castellano, S., Mugnozza, G.S., Russo, G., Briassoulis, D., Mistriotis, A., Hemming, S. and Waaijenberg, D. 2008. Plastic Nets in Agriculture: A General Review of Types and Applications. *Applied Engineering in Agriculture*, 24(6), pp.799-808.

Carte, A.E. 1967. Areal Hail Frequency. *Journal of Applied Meteorology*, 6(2), pp.336-338.

Carte, A.E. 1977. Hail Damage to Agriculture and Its Prevention. *South African Journal of Science*, 73, pp.327-330.

Carte, A.E. and Held, G. 1978. Variability of Hailstorms on the South African Plateau. *Journal of Applied Meteorology*, 17(3), pp.365-373.

Cecil, D.J. and Blankenship, C.B. 2012. Toward a Global Climatology of Severe Hailstorms as Estimated by Satellite Passive Microwave Imagers. *Journal of Climate*, 25(2), pp.687-703.

Changnon Jr, S.A. 1977. The Scales of Hail. *Journal of Applied Meteorology*, 16(6), pp.626-648.

Changnon Jr, S.A. and Ivens, J.L. 1981. History Repeated: The Forgotten Hail Cannons of Europe. *Bulletin of the American Meteorological Society*, 62(3), pp.368-375.

Changnon, S. A. 1999. Data and Approaches for Determining Hail Risk in the Contiguous United States. J*ournal of Applied Meteorol*ogy, 38, pp.1730–1739.

Changnon, S.A., Changnon, D. and Hilberg, S.D. 2009. *Hailstorms Across the Nation: An Atlas About Hail and Its Damages* [online]. ISWS Contract Report CR 2009-12, Illinois, pp.1-92. Available from: http://hdl.handle.net/2142/15156 [accessed 29 June 2019].

Chartan, Erol Kevin, Wright, J., and Landwehr, G. 2018. *Comparing the Value of Improved Variable Renewable Energy Forecasting Accuracy in South African and United States Power Systems.* Presented at WindAc 2018, Cape Town, South Africa, 5-6 November 2018. Available from: https://www.osti.gov/servlets/purl/1481731 [accessed 6 July 2020].

Christodoulou, M. and Sioutas, M. 2014. Supercell storms in Northern and Central Greece. Proceedings of Twelfth Panhellenic Conference of Meteorology, *Climatology and Atmospheric Physics*, Heraklion, Greece, 1, pp.186-191.

Cică, R., Burcea, S. and Bojariu, R., 2015. Assessment of Severe Hailstorms and Hail Risk Using Weather Radar Data. *Meteorological Applications*, 22(4), pp.746-753.

Clark-Ginsberg, A. and Roberts, S. 2020. *Disaster Reporting and Its Impacts on Policy and Inequities,* 16 November 2020. Available from: https://www.rand.org/blog/2020/11/disaster-reporting-and-its-impacts-on-policy-and-inequities.html [accessed 10 February 2023].

Coetzee, M. 2011. 'Friends and Pests', *Sunday World,* 23 January.

Cokayne, R. 2013. 'Motor Ferry Strike Nears End, But Hail Adds To…', *The Cape Times,* 6 December, pp.18.

Cook, K.H. 2000. The South Indian Convergence Zone and Interannual Rainfall Variability Over Southern Africa*. Journal of Climate*, 13(21), pp.3789-3804.

Converse, C.M. 2020. Environmental Discriminators for Significant Tornadoes and Hail in the US Using Proximity Soundings (Doctoral Dissertation, Northern Illinois University).

Cotton, W.R. and Pielke Sr, R.A. 2007. *Human Impacts on Weather and Climate.* Cambridge University Press.

Cotton, W.R., Bryan, G. and van den Heever, S.C. 2011. Cumulonimbus Clouds and Severe Convective Storms. *International Geophysics,* 99, pp. 315-454.

Courtier, B. 2020. Representing Thunderstorm Electrification for Lightning Forecast Evaluation (Doctoral Dissertation, University of Reading).

Crétat, J., Richard, Y., Pohl, B., Rouault, M., Reason, C. and Fauchereau, N. 2012. Recurrent Daily Rainfall Patterns Over South Africa and Associated Dynamics During the Core of the Austral Summer. *International Journal of Climatology*, 32(2), pp.261-273.

Crotty, A. 2014. 'Grape Farmers Cash in On Falling Rand, Good Crops', *The Cape Times,* 4 February, pp.13.

Crow, D.A., Berggren, J., Lawhon, L.A., Koebele, E.A., Kroepsch, A. and Huda, J. 2017. Local Media Coverage of Wildfire Disasters: An Analysis of Problems and Solutions in Policy Narratives. *Environment and Planning C: Politics and Space*, 35(5), 849-871.

Dallas, H.F. and Rivers-Moore, N. 2014. Ecological Consequences of Global Climate Change for Freshwater Ecosystems in South Africa. *South African Journal of Science*, 110(5-6), pp.1-11.

Daron, J., Burgin, L., Janes, T., Jones, R.G. and Jack, C. 2019. Climate Process Chains: Examples from Southern Africa. *International Journal of Climatology*, 39(12), pp.4784-4797.

Davis-Reddy, C.L. and Vincent, K. 2017. *Climate Risk and Vulnerability: A Handbook for Southern Africa (2nd Ed).* CSIR, Pretoria, South Africa.

Department of Environmental Affairs (DEA). 2013. Long Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Change Implications for the Biodiversity Sector in South Africa. Pretoria, South Africa.

De Coning, E. and Adam, B.F., 2000. The Tornadic Thunderstorm Events During the 1998-1999 South African Summer. *Water SA-Pretoria*, 26(3), pp.361-376.

De Kock, W.M., Blamey, R.C. and Reason, C.J.C. 2021. Large Summer Rainfall Events and their Importance in Mitigating Droughts Over the South Western Cape, South Africa. *Journal of Hydrometeorology*, 22(3), pp.587-599.

De Kraker, A.M. 2006. Historical Climatology, 1950-2006. An Overview of a Developing Science with a Focus on the Low Countries. Belgeo. *Revue Belge de Géographie*, (3), pp.307-338.

Del Rosario Prieto, M. and Herrera, R.G. 2009. Documentary Sources from South America: Potential for Climate Reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 281(3-4), pp.196-209.

Dieling, C., Smith, M. and Beruvides, M. 2020. Review of Impact Factors of the Velocity of Large Hailstones for Laboratory Hail Impact Testing Consideration. *Geosciences*, 10(12), pp. 1-16.

Diamond Fields Advertiser. 5 January 2016. What Will 2016 Bring For SA. Page 4.

Diepersloot, J. 2012. Developing an Advocacy Program for Hail Cannons in Agricultural Practices, pp.1-41.

Dimitrova, T., Mitzeva, R., Pisarova, Y., Betz, H.D. and Peneva, E., 2013. Relationship between Lightning Characteristics and Radar Estimated Parameters During Pre-Severe and Severe Stages of Hail Producing Thunderstorms Developed Over Bulgaria. In: *7th European Conference on Severe Storms ECSS2013*, pp. 3-7.

District Mail. 15 May 2012. Save for a Rainy Day. Page 12

Dong, Y., Zha, Q., Zhang, H., Kou, G., Fujita, H., Chiclana, F. and Herrera-Viedma, E. 2018. Consensus Reaching in Social Network Group Decision Making: Research Paradigms and Challenges. *Knowledge-Based Systems*, 162, pp.3-13.

Dowdy, A.J., Soderholm, J., Brook, J., Brown, A. and McGowan, H. 2020. Quantifying Hail and Lightning Risk Factors Using Long-Term Observations Around Australia. *Journal of Geophysical Research: Atmospheres*, 125(21), Article p.2020JD033101.

Dungworth, D. 2011. The Value of Historic Window Glass. *The Historic Environment: Policy & Practice,* 2(1), pp.21-48.

Du Plessis, J.A. and Schloms, B. 2017. An Investigation into the Evidence of Seasonal Rainfall Pattern Shifts in The Western Cape, South Africa. *Journal of the South African Institution of Civil Engineering*, *59*(4), pp.47-55.

Dyson, L. 4 January 2016. The Science Behind Hail. Available from: https://www.up.ac.za/research-matters/news/post_2996482-the-science-behind-hail [accessed 15 June 2022].

Emersic, C., Heinselman, P.L., MacGorman, D.R. and Bruning, E.C. 2011. Lightning Activity in a Hail-Producing Storm Observed with Phased-Array Radar. *Monthly Weather Review*, 139(6), pp.1809-1825.

Engelbrecht, F.,28 March Adegoke, J., Bopape, M.J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., Ichoku, C. and Gatebe, C. 2015a. Projections of Rapidly Rising Surface Temperatures Over Africa Under Low Mitigation. *Environmental Research Letters*, 10(8), Article p.085004.

Engelbrecht, C.J., Landman, W.A., Engelbrecht, F.A. and Malherbe, J. 2015b. A Synoptic Decomposition of Rainfall Over the Cape South Coast of South Africa. *Climate Dynamics*, 44(9-10), pp.2589-2607.

Engelbrecht, C.J. and Landman, W.A. 2016. Interannual Variability of Seasonal Rainfall Over the Cape South Coast of South Africa and Synoptic Type Association. *Climate Dynamics*, 47(1), pp.295-313.

FAO, 2007. Annual Report. Food and Agricultural Organization of the United Nations.

FAO, 2015. Annual Report. Food and Agricultural Organization of the United Nations.

Fauchereau, N., Trzaska, S., Rouault, M. and Richard, Y. 2003. Rainfall Variability and Changes in Southern Africa During the 20th Century in the Global Warming Context. *Natural Hazards*, 29(2), pp.139-154.

Federer, B., 1977. Methods And Results of Hail Suppression in Europe and in the USSR. In *Hail: A Review of Hail Science and Hail Suppression*. Boston: American Meteorological Society, pp.215-223.

Feely, S. 1997. ‘Finding Recurring Growth: Rentsure Holdings’, *Financial Mail*, 28 March.

Field, P.R., Hand, W., Cappelluti, G., McMillan, A., Foreman, A., Stubbs, D. and Willows, M. 2010. Hail Threat Standardization. *FINAL Report for EASA.2008.OP.25*, 20 November 2009, pp.1-130.

Flemming, L. 1935. ‘Hailing the Hail’, *Rand Daily Mail,* 7 March, pp.8.

Fluck, E., Kunz, M., Geissbuehler, P. and Ritz, S.P. 2020. Radar-Based Assessment of Hail Frequency in Europe. *Natural Hazards and Earth System Sciences*, 21(2), pp.683-701.

Fruk, G., Fruk, M., Vuković, M., Buhin, J., Jatoi, M.A. and Jemrić, T. 2016. Colouration Of Apple cv. ‘Braeburn’grown Under Anti-Hail Nets in Croatia. *Acta Horticulturae et Regiotecturae*, 19(s1), pp.1-4.

Gallo, K., Smith, T., Jungbluth, K. and Schumacher, P. 2012. Hail Swaths Observed from Satellite Data and Their Relation to Radar and Surface-Based Observations: A Case Study from Iowa in 2009. *Weather and Forecasting*, 27(3), pp.796-802.

Gandorfer, M., Hartwich, A. and Bitsch, V. 2015, May. Hail Risk Management in Fruit Production: Anti-Hail Net Versus Hail Insurance in Germany. In: *XVIII International Symposium on Horticultural Economics and Management,* 1132, pp. 141-146.

Gavrilov, M.B., Marković, S.B., Zorn, M., Komac, B., Lukić, T., Milošević, M. and Janićević, S. 2013. Is Hail Suppression Useful in Serbia? –General Review and New Results. *Acta Geographica Slovenica*, 53(1), pp.165-179.

Geldenhuys, H. 2013. 'The 15 Minutes that Devastated Fruit Industry', *Weekend Argus*, 23 November, pp.8.

Gibbs, J. 2016. Global Hail. Available from: https://www.jdsupra.com/legalnews/global-hail-62131/ [Accessed 21 November 2019]

Gilbert, D.B., Boe, B.A. and Krauss, T.W. 2016. Twenty Seasons of Airborne Hail Suppression in Alberta, Canada. *Journal of Weather Modification*, 48, pp.68-92.

Grant, B., Huchzermeyer, D. and Hohls, B. 2014. Manual For Fish Kill Investigations in South Africa. Report for the Water Research Commission. *WRC Report No. TT*, 589, p.1-108.

Green, J. 2006. 'Pit Stop', *Business Day*, 14 March.

Grobler, R.R., 2003. A Framework for Modelling Losses Arising from Natural Catastrophes in South Africa (Doctoral Dissertation, University of Pretoria).

Groenemeijer, P.H. and Van Delden, A. 2007. Sounding-Derived Parameters Associated with Large Hail and Tornadoes in the Netherlands. *Atmospheric Research*, 83(2-4), pp.473-487.

Goltz, J.D. 1984. Are the News Media Responsible for the Disaster Myths? A Content Analysis of Emergency Response Imagery. *International Journal of Mass Emergencies and Disasters*, 2(3), 345-368.

Goraj, Z.J. and Kustron, K. 2018. Review Of Current Research Trends in Bird Strike and Hail Impact Simulations on Wing Leading Edge. *Aircraft Engineering and Aerospace Technology*, 90(4), pp.602-612.

Guerrero, V.M., Orozco, J.A., Romo, A. and Gardea, A.A. 2002. The Effect of Hail Nets and Ethephon on Color Development Of'redchief Delicious' Apple Fruit in The Highlands of Chihuahua, Mexico. *Journal of the American Pomological Society,* 56(3), p.132-135.

Haby, J. n.d. Habytime Mini Lecture 64: Hail Streak. Available from: https://www.theweatherprediction.com/habyhints2/662/ [accessed 15 June 2022].

Hailstorm Checklist. 2018. Allianz Risk Consulting. Available from: https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/pdfs-risk-advisory/checklists/ARC-Hailstorm-Checklist-EN.pdf [accessed 15 June 2022].

Hail Free Solution. 2021. Available from: https://hailfreesolutions.com/how-bad-can-hail-damage-affect-car-value/ [accessed 15 June 2022].

Harper, C. 2015. 'Huge Repair Bills After Hailstorm', *South Coast Fever*, 6 March, pp.2.

Hart, N.C.G., Reason, C.J.C. and Fauchereau, N. 2010. Tropical–Extratropical Interactions Over Southern Africa: Three Cases of Heavy Summer Season Rainfall. *Monthly Weather Review*, 138(7), pp.2608-2623.

Hart, N.C., Reason, C.J. and Fauchereau, N. 2013. Cloud Bands Over Southern Africa: Seasonality, Contribution to Rainfall Variability and Modulation by the MJO. *Climate Dynamics*, 41(5), pp.1199-1212.

Hatfield, J.L. and Prueger, J.H. 2015. Temperature Extremes: Effect on Plant Growth and Development. *Weather And Climate Extremes*, *10*, pp.4-10.

Havenga, H., Burger, R.P., Piketh, S.J. and Bruyere, C. 2016. Evaluating WRF's Dbz Diagnostic Feature on the 28 November Hailstorm Over the South African Highveld. *SASAS Conference 2016*, 31 October - 1 November 2016, Cape Town, South Africa, pp.50-54.

Havenga, H. 2018. Characteristics of Hailstorms Over the South-African Highveld (Doctoral Dissertation, North-West University).

Heildorn, K.C. 2002. Weather Phenomenon and Elements: Hail Formation. Available from: http://www.heidorn.info/keith/weather/elements/hailform.htm [accessed 18 October 2019]

Held, G. 1974. Hail Frequency in Pretoria-Witwatersrand Area during 1962 to 1972. *Pure and Applied Geophysics*, 7, pp.185-197.

Held, G. 1978. The Probability of Hail in Relation to Radar Echo Heights on the South African Highveld. *Journal of Applied Meteorology,* 17, pp.273-284.

Henderson, R. 2018. 'No Cover from Cape's Burning Drought for Urban Business', *Sunday Times,* 11 February.

Herman, R.L. and Meyer, F.P. 1990. Fish Kills Due to Natural Causes. *Resources Publication*, 177, pp.41-44.

Hohl, R., Schiesser, H.H. and Aller, D. 2002. Hailfall: The Relationship Between Radar-Derived Hail Kinetic Energy and Hail Damage to Buildings. *Atmospheric Research*, 63(3-4), pp.177-207.

Houston, J.B., Pfefferbaum, B. and Rosenholtz, C.E. 2012. Disaster News: Framing and Frame Changing in Coverage of Major US Natural Disasters, 2000–2010. *Journalism & Mass Communication Quarterly*, 89(4), pp.606-623.

Howard, E., Washington, R. and Hodges, K.I. 2019. Tropical Lows in Southern Africa: Tracks, Rainfall Contributions, and the Role Of ENSO. *Journal of Geophysical Research: Atmospheres*, 124(21), pp.11009-11032.

Huber, D.G. and Gulledge, J. 2011. Extreme Weather and Climate Change: Understanding the Link, Managing the Risk. Arlington: *Pew Center on Global Climate Change*, pp.1-13.

Hunsche, M., Blanke, M.M. and Noga, G.2010. Does the Microclimate Under Hail Nets Influence Micromorphological Characteristics of Apple Leaves and Cuticles? *Journal of Plant Physiology*, 167(12), pp.974-980.

Jakopic, J., Veberic, R. and Stampar, F. 2007. The Effect of Reflective Foil and Hail Nets on the Lighting, Color and Anthocyanins Of 'Fuji' Apple. *Scientia Horticulturae*, 115(1), pp.40-46.

Janek. 2013. Glass and Glazing as a Construction Element. Available from: https://www.sans10400.co.za/glass-and-glazing/ [accessed 10 June 2022].

Jayababu, A., Arumugam, V., Rajesh, B. and Suresh Kumar, C. 2020. Investigation of Indentation Damage Resistance on Normal and Inclined Plane of Glass/Epoxy Composite Laminates Using Acoustic Emission Monitoring. *Journal of Composite Materials*, 54(21), pp.2953-2964.

Jekot, B.P. 2010. Review of Changes in Ceramic Tile Installation in South Africa. In: *Proc. Qualicer'10- 11th World Congress on Ceramic Tile Quality,* pp. 101-126.

Jury, M.R. 2015. Passive Suppression of South African Rainfall by the Agulhas Current. *Earth Interactions*, 19(13), pp.1-14.

Karacostas, T.S. 1991. Some Characteristics of Convective Cells in the Greek National Hail Suppression Program. *Geofizika*, 8(1), pp.43-50.

Karagioras, A. and Kourtidis, K. 2021. A Study of the Effects of Rain, Snow and Hail on the Atmospheric Electric Field Near Ground. *Atmosphere*, 12(8), p.996-1009.

Keeton, C. 2011. 'Culture. Healer in Two Worlds', *Sunday Times,* 2 April.

Kelbe, B.E. 1984. Cumulus Cloud Characteristics for the Eastern Transvaal Lowveld. *Water SA*, 10, pp.81-90.

Khanna P, Nagrath K, Mangrulkar A. 2011. Climate and Construction – An Impact Assessment. Project Report to CDKN, 2011. *Development Alternatives Group*, New Delhi, pp.1-16.

Kings, S. 2016. 'Full Horror of Drought Emerges', *Mail & Guardian*, 29 January.

Kneale, J. and Randalls, S., 2014. Invisible Atmospheric Knowledges in British Insurance Companies, 1830-1914. *History of Meteorology*, 6, pp.35-52.

Knoetzee, D. 2013. 'Hail Destroys Harvest Hopes of Fruit Farmers', *Cape Argus,* 21 November, p.18.

Korea Aviation and Railway Accident Investigation Board. 2008. A321, En-Route, Gimpo South Korea, 2006. Available from: https://www.skybrary.aero/accidents-and-incidents/a321-en-route-gimpo-south-korea-2006 [accessed 15 June 2022].

Kührt, U., Samietz, J. and Dorn, S. 2006. Effect Of Plant Architecture and Hail Nets on Temperature of Codling Moth Habitats in Apple Orchards. *Entomologia Experimentalis Et Applicata,* 118(3), pp.245-259.

Krauss, T.W. and Santos, J.R. 2004. Exploratory Analysis of the Effect of Hail Suppression Operations on Precipitation in Alberta. *Atmospheric Research*, 71(1-2), pp.35-50.

Kruger, AC, Goliger, AM, Retief, JV and Sekele, S. 2010. Strong Wind Climatic Zones in South Africa. *Wind & Structures,* 13(1), pp. 37-55.

Lacagnina, M. 2007. Hammered By Hail: Flight Crew Faulted for Inadequate Use of Radar Information. *Aerosafety World- October 2007*, 2(10), pp.1-68.

Laker, M., Van Heerden, P. And Stevens, J. 2012. Training Material for Extension Advisors in Irrigation Water Management. *Water Research Commision*, SA, pp.1-113.

Landman, W.A., Malherbe, J., Engelbrecht, F.2017. South Africa's Present-Day Climate. In: Mambo J, Faccer K (Eds) *Understanding the Social and Environmental Implications of Global Change. Africa Sun Media,* Stellenbosch, pp.7–12.

Langa, E. 2016. 'Voice Saved Me from Death', *Daily Sun*, 4 October, pp.7.

Lemon, L.R., Parker, S. and North Platte, N.E. 1996. The Lahoma Storm Deep Convergence Zone: Its Characteristics and Role in Storm Dynamics and Severity. In: *18th Conference on Severe Local Storms*, 19-23 February 1996, San Francisco, CA, pp.1-6.

Le Roux, N.J. and Olivier, J. 1996. Modelling Hail Frequency Using a Generalized Additive Interactive Technique. *South African Geographical Journal,* 78(1), pp.7-12.

Lennard, C. and Hegerl, G. 2015. Relating Changes in Synoptic Circulation to the Surface Rainfall Response Using Self-Organising Maps. *Climate Dynamics*, 44(3-4), pp.861-879.

Lepore, C., Tippett, M.K. and Allen, J.T. 2017. ENSO-Based Probabilistic Forecasts of March–May US Tornado and Hail Activity. *Geophysical Research Letters*, 44(17), pp.9093-9101.

Li, M., Zhang, Q. and Zhang, F. 2016. Hail Day Frequency Trends and Associated Atmospheric Circulation Patterns Over China During 1960–2012. *Journal of Climate*, 29(19), pp.7027-7044.

Lindsay, B.R. 2011. Social Media and Disasters: Current Uses, Future Options, and Policy Considerations. *CRS Report for Congress*, pp.1-10.

Littlefield, R.S. and Quenette, A.M. 2007. Crisis Leadership and Hurricane Katrina: The Portrayal of Authority by the Media in Natural Disasters. *Journal of Applied Communication Research*, 35(1), pp.26-47.

Liu, N., Liu, C. and Lavigne, T. 2019. The Variation of the Intensity, Height, and Size of Precipitation Systems Will El Nino-Southern Oscillation in the Tropics and Subtropics. *Journal of Climate*, 32(4), pp.4281-4297.

Loewe, M. 2012a. 'Dakota Not Designed to be Flying in 21st Century', *Daily Dispatch,* 7 December.

Loewe, M. 2012b. 'Plane Likely Damaged Before Crashing', *Daily Dispatch,* 10 December.

Lucchini, R.G., Hashim, D., Acquilla, S., Basanets, A., Bertazzi, P.A., Bushmanov, A., Crane, M., Harrison, D.J., Holden, W., Landrigan, P.J. and Luft, B.J. 2017. A Comparative Assessment of Major International Disasters: The Need for Exposure Assessment, Systematic Emergency Preparedness, And Lifetime Health Care. *BMC Public Health*, 17(1), pp.1-12.

Luterbacher, J., Rickli, R., Tinguely, C., Xoplaki, E., Schüpbach, E., Dietrich, D., Hüsler, J., Ambühl, M., Pfister, C., Beeli, P. and Dietrich, U. 2000. Monthly Mean Pressure Reconstruction for the Late

Maunder Minimum Period (AD 1675–1715). *International Journal of Climatology*, 20(10), pp.1049-1066.

MacGregor, D. 2008. ‘Tornado Tears its Way Through Grahamstown’, *Daily Dispatch*, 9 October.

Machakela, G. and Petersen, G. 2008. ‘8 Die in Two Days of Hail Chaos’, *Daily Sun*, 12 November, pp.2.

Macron, C., Pohl, B., Richard, Y. and Bessafi, M. 2014. How Do Tropical Temperate Troughs Form and Develop Over Southern Africa? *Journal of Climate*, 27(4), pp.1633-1647.

Mader, G.N. 1979. Numerical Study of Storms in the Transvaal. *South African Geography Journal*, 61, pp.86-98.

Mahony, M. and Endfield, G. 2018. Climate and Colonialism. *Wiley Interdisciplinary Reviews: Climate Change*, 9(2), pp.1-16.

Marcos, J.L., Sánchez, J.L., Merino, A., Melcón, P., Mérida, G. and García-Ortega, E. 2021. Spatial And Temporal Variability of Hail Falls and Estimation of Maximum Diameter from Meteorological Variables. *Atmospheric Research*, 247, Article p.105142.

Maré, F.A. 2014. Evaluating Crop Insurance as Production Risk Management Strategy (Doctoral Dissertation, University of the Free State).

Markowski, P. and Richardson, Y. 2014. Tornado Formation. *Physics Today*, 67(9), pp.26-31.

Marshall, T. and Herzog, R. 1999. Protocol for Assessment of Hail-Damaged Roofing. In: *North American Conf. on Roofing Technology*, pp. 40-46.

Marshall, T. P., R. F. Herzog, S. J. Morrison, and S. R. Smith, 2002. Hail Damage Threshold Sizes for Common Roofing Materials. In: *21st Conf. on Severe Local Storms*, San Antonio, TX. *American Meteorology Society*, 25, pp.95–98.

Martins, J.A., Brand, V.S., Capucim, M.N., Felix, R.R., Martins, L.D., Freitas, E.D., Gonçalves, F.L., Hallak, R., Dias, M.A.S. and Cecil, D.J. 2017. Climatology Of Destructive Hailstorms in Brazil. *Atmospheric Research*, 184, pp.126-138.

Masereka, E.M., Ochieng, G.M. and Snyman, J. 2018. Statistical Analysis of Annual Maximum Daily Rainfall for Nelspruit and its Environs. *Jàmbá: Journal of Disaster Risk Studies*, 10(1), pp.1-10.

Mather, G.K., 1977. An Analysis of a Possible Crop Response to Hail Suppression Seeding: The Nelspruit Hail Suppression Project. *Journal of Applied Meteorology and Climatology*, 16(9), pp.959-970.

Mather, G.K., Bigg, E.K. and Renton, S. 1990. Apparent Persistence Effects in the Nelspruit Area from Silver Iodide Seeding for Hail Suppression. *Journal of Applied Meteorology (1988-2005*), pp.806-811.

Matthewman, S. 1998. Weather-Modification in South Africa: Public Reactions to a ‘Social Science’. *Society in Transition,* 29(3-4), pp.104-117.

Mauk, P.A. and Shea, T. 2002. Questions and Answers to Citrus Management. University of California, County of Riverside and US Department of Agriculture Cooperating.

McFarlene, N. 2014. *Bolander,* 26 November, pp.7.

Mdlankomo, L. 2012. 'Wits Junction Building Under Investigation', *Wits Vuvuzela,* 21 September.

Mészáros, M., Bělíková, H., Čonka, P. and Náměstek, J. 2019. Effect of Hail Nets and Fertilization Management on the Nutritional Status, Growth and Production of Apple Trees. *Scientia Horticulturae*, 255, pp.134-144.

Mezher, R.N., Doyle, M. and Barros, V. 2012. Climatology of Hail in Argentina. *Atmospheric Research*, 114, pp.70-82.

McNutt, M. 18 October 1994. 113 mph Wind Hits Lahoma Storm Strips Trees, Ruins 28 Residences. Available: https://www.oklahoman.com/story/news/1994/08/18/113-mph-wind-hits-lahoma-storm-strips-trees-ruins-28-residences/62417114007/ [accessed: 15 June 2022].

Mhlana, 2015. '5 Die After Lightning Strikes at Funeral', *The New Age*, 14 December, pp.3.

Midgley, S.J.E. and Lötze, E. 2008. Climate Change in The Western Cape of South Africa: Trends, Projections and Implications for Chill Unit Accumulation. In: *IX International Symposium on Integrating Canopy, Rootstock and Environmental Physiology in Orchard Systems,* 903, pp. 1127-1134.

Miles, B. and Morse, S. 2007. The Role of News Media in Natural Disaster Risk and Recovery. *Ecological Economics*, 63(2-3), pp.365-373.

Mnisi, O. 2018. 'Out in the Cold: Storm Wreaks Havoc', *Daily Sun,* 11 December, pp.7.

Mpandeli, S., Nesamvuni, E. and Maponya, P. 2015. Adapting to the Impacts of Drought by Smallholder Farmers in Sekhukhune District in Limpopo Province, South Africa. *Journal of Agricultural Science*, 7(2), pp.115-124.

Moeletsi, M.E., Walker, S., and Landman, W.A. 2011. ENSO and Implications on Rainfall Characteristics with Reference to Maize Production in the Free State Province of South Africa. *Physics And Chemistry of The Earth, Parts A/B/C*, 36(14-15), pp.715-726.

Molekwa, S. 2013. Cut-Off Lows Over South Africa and their Contribution to the Total Rainfall of The Eastern Cape Province (Doctoral Dissertation, University of Pretoria).

Morgan, G.M. 2008. The Return of The Anti-Hail Cannons. *Weatherwise*, 61(4), pp.14-19.

Morgan, K.T., Wheaton, T.A., Castle, W.S. and Parsons, L.R. 2009. Response of Young and Maturing Citrus Trees Grown on a Sandy Soil to Irrigation Scheduling, Nitrogen Fertilizer Rate, and Nitrogen Application Method. *Horticulture Science*, 44(1), pp.145-150.

Moyo, E.N. and Nangombe, S.S. 2015. Southern Africa's 2012–13 Violent Storms: Role of Climate Change. *Procedia IUTAM*, 17, pp.69-78.

Mthalane, V. 2015. 'Storm Tears Roof Off', *South Coast Fever*, 3 April, pp.4.

Muchuru, S., Landman, W.A., DeWitt, D. and Lötter, D. 2014. Seasonal Rainfall Predictability over the Lake Kariba Catchment Area. *Water SA*, 40(3), pp.461-470.

Munoz, L.M.P. 2017. Seeding Change in Weather Modification Globally. *WMO, Climate*, 66(1). Available from: https://public.wmo.int/en/resources/bulletin/seeding-change-weather-modification-globally [accessed 20 July 2022]

Murthy, D. and Longwell, S.A. 2013. Twitter And Disasters: The Uses of Twitter During the 2010 Pakistan Floods. *Information, Communication & Society*, 16(6), pp.837-855.

Muofhe, T.P., Chikoore, H., Bopape, M.J.M., Nethengwe, N.S., Ndarana, T. and Rambuwani, G.T. 2020. Forecasting Intense Cut-Off Lows in South Africa using the 4.4 km Unified Model. *Climate*, 8(11), pp.129-149.

Nash, D.J. and Adamson, G.C. 2014. Recent Advances in the Historical Climatology of the Tropics and Subtropics. *Bulletin of the American Meteorological Society*, 95(1), pp.131-146.

Nash, D.J., Klein, J., Endfield, G.H., Pribyl, K., Adamson, G.C. and Grab, S.W. 2019. Narratives of Nineteenth Century Drought in Southern Africa in Different Historical Source Types. *Climatic Change,* 152(3), pp.1-19.

Negi, V.S., Maikhuri, R.K., Pharswan, D., Thakur, S. and Dhyani, P.P., 2017. Climate Change Impact in the Western Himalaya: People's Perception and Adaptive Strategies. *Journal of Mountain Science*, 14(2), pp.403-416.

Neidigk, S.O., Roach, D.P., Duvall, R.L., Westlund, D. and Galella, D. 2017. Detection and Characterization of Hail Impact Damage in Carbon Fiber Aircraft Structures. Sandia National Laboratories.

Ngcobo, G. 2012. 'Waging War on Monkeys - Better Ways to Deal With', *The Witness*, 24 January, pp.4.

Ni, X., Zhang, Q., Liu, C., Li, X., Zou, T., Lin, J., Kong, H. and Ren, Z., 2017. Decreased Hail Size in China Since 1980. *Scientific Reports*, 7(1), Pp.1-6.

Nisi, L., Hering, A., Germann, U. and Martius, O., 2018. A 15-Year Hail Streak Climatology for the Alpine Region. *Quarterly Journal of the Royal Meteorological Society*, 144(714), pp.1429-1449.

Nonyane, M. 1975. 'Hail Damage: Don't Spend Too Much', *Rand Daily Mail,* 27 January, pp.1.

Norton, I. 1979. 'Farmers' Yes to Cloud Seeding', *Rand Daily Mail,* 1 August, pp.9.

Noy, I. and Yonson, R., 2018. Economic vulnerability and resilience to natural hazards: A survey of concepts and measurements. *Sustainability*, 10(8), p.2850.

Ntelekos, A.A., Smith, J.A., Donner, L., Fast, J.D., Gustafson Jr, W.I., Chapman, E.G. and Krajewski, W.F., 2009. The Effects of Aerosols on Intense Convective Precipitation in the Northeastern United States. Quarterly Journal of the Royal Meteorological Society: A Journal of the Atmospheric Sciences. *Applied Meteorology and Physical Oceanography*, 135(643), pp.1367-1391.

O'Connell, C.J. and Mills, A.J. 2003. Making Sense of Bad News: The Media, Sensemaking, and Organizational Crisis. *Canadian Journal of Communication*, 28(3), 323-339.

Olivier, J. 1990. Hail in the Transvaal: Some Geographical and Climatological Aspects (Doctoral Dissertation, University of Johannesburg).

Olivier, J., and van Rensburg, P.A. 1992. The Impact of Hail on Transvaal Maize Production. *Agrekon*, 31(2), pp.62-73.

Pakiam, J.E. and Maybank, J. 1969. A Preliminary Survey of Some Lightning-Hailstorm Relationships. *Atmosphere*, 7(4), pp.131-143.

Palencia, C., Giaiotti, D., Stel, F., Castro, A. and Fraile, R. 2010. Maximum Hailstone Size: Relationship with Meteorological Variables. *Atmospheric Research*, 96(2-3), pp.256-265.

Palmer, A.R. and Ainslie, A.M. 2005. Grasslands of South Africa. *Grasslands of the World*, 34, p.77-120.

Peduzzi, P. 2019. The Disaster Risk, Global Change, and Sustainability Nexus. *Sustainability*, 11(4), pp.957-978.

Perez-Lugo, M. 2004. Media Uses in Disaster Situations: A New Focus on the Impact Phase. *Sociological Inquiry*, 74(2), pp.210-225.

Perry, A. 1995. Severe Hailstorm at Grahamstown in Relation to Convective Weather Hazards in South Africa. *Weather*, 50(6), pp.211-214.

Petersen, T. 1975. An Analysis of Thirteen Years of Commercial Hail Suppression in Central Alberta. *The Journal of Weather Modification*, 7(2), pp.153-170.

Petty, S.E. and Monhemius, N. 2021. Hail Fundamentals and General Hail-Strike Damage Assessment Methodology. In: *Forensic Engineering*, *CRC Press*, pp.21-64.

Pfister, C., Brázdil, R. and Barriendos, M. 2002. Reconstructing Past Climate and Natural Disasters in Europe Using Documentary Evidence. *Pages News*, 10(3), pp.6-8.

Pfister, C. and White, S. 2018. Evidence from the Archives of Societies: Personal Documentary Sources. In: *The Palgrave Handbook of Climate History*, Palgrave Macmillan, London, pp.49-65.

Phillipson, M.C., Emmanuel, R. and Baker, P.H. 2016. The Durability of Building Materials Under a Changing Climate. *Wiley Interdisciplinary Reviews: Climate Change*, 7(4), pp.590-599.

Picak, S., Liu, J., Hayrettin, C., Nasim, W., Canadinc, D., Xie, K., Chumlyakov, Y.I., Kireeva, I.V. and Karaman, I., 2019. Anomalous Work Hardening Behavior of Fe40Mn40Cr10Co10 High Entropy Alloy Single Crystals Deformed by Twinning and Slip. *Acta Materialia*, 181, pp.555-569.

Pidgeon, N. and Fischhoff, B. 2011. The Role of Social and Decision Sciences in Communicating Uncertain Climate Risks. *Nature Climate Change*, 1(1), pp.35-41.

Pienaar, N., Dyson, L.L. and Klopper, E. 2015. Atmospheric Anomalies During the 2012/13 Extreme Hail Seasons Over Gauteng. In: *Proceedings of the 31st Annual conference of South African Society for Atmospheric Sciences*, pp. 21-22.

Pieterse, C. 2015. 'Car Repairs Soar After Hail', *The Witness,* 20 January, pp.3.

Piketh, S. and Burger, R. 2014. *Hail in South Africa* [PowerPoint presentation]. Africa Conference: South African Insurance Association. Available from: https://www.researchgate.net/publication/303942645_Hail_in_South_Africa [accessed: 20 May 2019].

Pillay, K. 2012. 'Pouring for Ladysmith Residents', *Daily News,* 21 December, pp.6.

Pinker, S. 2018. *The Media Exaggerates News*. The Consequences of Distortion, 17 February 2018. Available from: https://www.theguardian.com/commentisfree/2018/feb/17/steven-pinker-media-negative-news [accessed September 2019].

Prabhakar, M., Gopinath, K.A., Reddy, A.G.K., Thirupathi, M. and Rao, C.S. 2019. Mapping Hailstorm Damaged Crop Area Using Multispectral Satellite Data. *The Egyptian Journal of Remote Sensing and Space Science*, 22(1), pp.73-79.

Prein, A.F. and Holland, G.J. 2018. Global Estimates of Damaging Hail Hazard. *Weather and Climate Extremes*, 22, pp.10-23.

Preston-Whyte, R.A. and Tyson, P.D. 1988. Atmosphere And Weather of Southern Africa. Oxford University Press.

Púčik, T., Groenemeijer, P., Rýva, D. and Kolář, M., 2015. Proximity Soundings of Severe and Non-Severe Thunderstorms in Central Europe. *Monthly Weather Review*, 143(12), pp.4805-4821.

Púčik, T. 2023. Major Hailstorms of 2022. Available from: https://www.essl.org/cms/author/tomas/#:~:text=Major%20hailstorms%20of%202022&text=The%20year%202022%20was%20another,already%20a%20record%2Dbreaking%20year [accessed 29 March 2023].

Punge, H.J. and Kunz, M. 2016. Hail Observations and Hailstorm Characteristics in Europe: A Review. *Atmospheric Research*, 176, pp.159-184.

Punge, H.J., Bedka, K.M., Kunz, M., Bang, S.D. and Itterly, K.F. 2021. Characteristics Of Hail Hazard in South Africa Based on Satellite Detection of Convective Storms. *Natural Hazards and Earth System Sciences Discussions*, pp.1-32.

PwC. October 2014. African Insurance Trends: Strategic and Emerging Trends in Insurance Markets in South Africa, Kenya and Nigeria. Part 1- South Africa.

Pyle, D.M. 2006. Severe convective storm risk in the Eastern Cape Province of South Africa (Doctoral Dissertation, Rhodes University).

Rabie, M.A. and Loubser, M. 1990. Legal Aspects of Weather Modification. *Comparative and International Law Journal of Southern Africa*, 23(2), pp.177-218.

Rae, K., Venter, W., Maliage, M. and Nurse, V. 2018. Significant Weather Over the Past Six Months. WeatherSmart News, South African Weather Services. August 2018. ISSN: 2414-8644.

Rao, V.U.M., Rao, B.B., Sikka, A.K., Rao, A.S., Singh, R. and Maheswari, M. 2014. Hailstorm Threat to Indian Agriculture: A Historical Perspective and Future Strategies. *Central Research Institution for Dryland Agriculture*, pp.1-44.

Ramluckan, T. 2016. Social Media as a Communication Tool During Crises and Disasters: A South African Governance Perspective (Doctoral Dissertation, University of Kwa-Zulu Natal).

Randalls, S. and Kneale, J. 2021. A Fragile Network: Effecting Hail Insurance in Britain, 1840–1900. *Enterprise & Society*, 22(3), pp.739-769.

Rand Daily Mail. 1 January 1905. Severe Hail Storm: Damage in the districts. Page 7.

Rand Daily Mail. 17 January 1905. A Record Hailstorm: Hundreds of Animals Killed. Page 7.

Rand Daily Mail. 15 September 1905. Rain and Storm: In the Transvaal. Page 8.

Rand Daily Mail. 5 February 1908. Hailstorm Concert. Page 8.

Rand Daily Mail. 26 November 1908. Roof Riddled by Hail. Page 2.

Rand Daily Mail. 7 November 1911. Recent Rains, Natives Killed by Hail, Much Stock Destroyed. Page 10.

Rand Daily Mail. 1 December 1911. The Recent Storm: Western Transvaal Losses. Page 7.

Rand Daily Mail. 19 February 1913. Hailstorms. Page 4.

Rand Daily Mail. 6 November 1914. After the Storm, Record Fall of Hail, Gardens Ruined.

Rand Daily Mail. 22 November 1918. Hailstorm Problem. Page 5.

Rand Daily Mail. 23 November 1920. Enormous Storm: Many Producers Ruined, Fruit and Vegetable Crops Destroyed. Page 5.

Rand Daily Mail. 13 October 1921. How To Make Money: Mysterious Hail Belts. Page 9.

Rand Daily Mail. 4 January 1922. Terrific Hail in O.F.S.: Much Damage Done. Page 2.

Rand Daily Mail. 28 October 1927. Heavy Rain on the East Rand: Hail Three Inches Deep in Primrose. Page 10.

Rand Daily Mai. 3 February 1928. Successful Fruit-Growing Near Johannesburg: The Example of Kew Orchards. Page 4.

Rand Daily Mail. 20 February 1928.Terrific Hailstorm on The Diggings. Page 7.

Rand Daily Mail. 22 October 1928. Acts Of God: The Law and the Hailstorm.

Rand Daily Mail. 19 October 1928. Hailstorm Havoc in the City: Scenes and Incidents in Yesterday's Visitation. Page 10.

Rand Daily Mail. 8 October 1929. Popular Double for Mr J.W. Radford at Turffontein: For the Relief Fund. Sentinel. Page 13.

Rand Daily Mail. 30 October 1929. Storms Over Johannesburg: Hail Can't Be Prevented but One Can Be Absolutely Safe from Lightning. Page 15.

Rand Daily Mail. 16 November 1931. Hail Kills 5000 Sheep: 20 Miles of Havoc. Page 11.

Rand Daily Mail. 13 September 1935. Farmers Baulk Hail Demon: Insurance Plans Success. Page 6.

Rand Daily Mail. 3 February 1936. 15 Dead; 7 Missing in Terrible Hailstorm. Page 9.

Rand Daily Mail. 12 February 1936. Hail Breaks Sheep' Legs. Page 14.

Rand Daily Mail. 25 November 1936. Devastating Hailstorms on Rand: Damage in City Suburbs and At Florida. Page 18.

Rand Daily Mail. 6 November 1937. What The Weather Did Yesterday: Hail Dismayed. Page 14.

Rand Daily Mail. 20 October 1938. City Golfers Struck by Lightning: Traffic Held Up by Hail and Mist. Page 2.

Rand Daily Mail. 14 November 1942. Newton Looks Up Again. Page 3.

Rand Daily Mail. 14 October 1948. Hail Injures Factory Workers. Page 9

Rand Daily Mail. 21 November 1949. Pretoria Has Another Storm. Page 9.

Rand Daily Mail. 23 December 1949. Pretoria Hail £9000 Short. Page 6.

Rand Daily Mail. 22 September 1950. Co-Operative Board Will Give Farmers Hail, Fire Insurance. Page 12.

Rand Daily Mail. 19 November 1951. Hail Clouds Can Be Nullified, Farmers Told. Page 7.

Rand Daily Mail. 3 December 1952. Can Hail Damage Be Prevented? Page 10.

Rand Daily Mail. 24 November 1955. National Disaster Fund. Page 5.

Rand Daily Mail. 14 December 1956. Hail Kills Sheep. Page 15.

Rand daily Mail. 3 November 1959. Families Quit Homes: Heavy Damage as the Hail Pounds Rand. Page 1.

Rand Daily Mail. 29 November 1960. Hail Gun to Test Materials. Page 3.

Rand Daily Mail. 15 November 1963. Shad Fisherman Disappointed by Flooded Rivers. Page 31.

Rand Daily Mail. 16 May 1964. National Disaster Fund. Page 5.

Rand Daily Mail. 6 June 1964. Rall Wants to Fight Hail with Rockets, Radar. Page 2.

Rand Daily Mail. 2 December 1966. Hail Traps Men Sitting on 'Bomb'. Page 6.

Rand Daily Mail. 22 January 1972. Seeding the High Cumulus Clouds to Make Rain. Page 11.

Rand Daily Mail. 24 February 1972. We've Had Enough, Farmers Tell Rainmakers. Page 1.

Rand Daily Mail. 29 April 1972. Control Bids to Change Weather. Page 4.

Rand Daily Mail. 27 July 1972. Anti-Hail Project Continues. Page 16.

Rand Daily Mail. 22 November 1972. Aerial Battle Against Hail Gets Farmers' Thumbs-Up: Jet Planes May Help Hail. Page 9.

Rand Daily Mail. 15 October 1973. Hail Havoc at Brits. Page 2.

Rand Daily Mail. 12 November 1973. Anti-Hail Operations Continue. Page 5.

Rand Daily Mail. 17 November 1973. Metal-Based Tiles a Great Success; Slate- Pricey but Attractive; Concrete Is the Cheapest. Page 7.

Rand Daily Mail. 21 January 1974. Hail Havoc at Brits. Page 3.

Rand Daily Mail. 21 January 1975. More Rent for Unsafe Houses Unfair. Page 1.

Rand Daily Mail. 24 January 1975. Co-Op Blamed by Farmers for Drought. Page 9.

Rand Daily Mail. 10 October 1977. Storm Rips Off Roof. Page 3.

Rand daily Mail. 11 March 1978. Roofing Materials are Still on Top. Page 9.

Raupach, T.H., Martius, O., Allen, J.T., Kunz, M., Lasher-Trapp, S., Mohr, S., Rasmussen, K.L., Trapp, R.J. and Zhang, Q. 2021. The Effects of Climate Change on Hailstorms. *Nature Reviews Earth & Environment*, 2(3), pp.213-226.

Rattanpal, H.S., Singh, G., Singh, S. and Arora, A. 2017. Citrus Cultivation in Punjab. Punjab Agricultural University, Ludhiana, India, pp.1-128.

Rattien, S. 1990. The Role of the Media in Hazard Mitigation and Disaster Management. *Disasters*, 14(1), pp.36-45.

Reason, C.J.C. 2001. Subtropical Indian Ocean SST Dipole Events and Southern African Rainfall. *Geophysical Research Letters,* 28(11), pp.2225-2227.

Reason, C.J.C. 2002. Sensitivity of the Southern African Circulation to Dipole Sea-Surface Temperature Patterns in the South Indian Ocean. In: *International Journal of Climatology: A Journal of the Royal Meteorological Society,* 22(4), pp.377-393.

Reason, C.J.C. and Jagadheesha, D. 2005. Relationships between South Atlantic SST Variability and Atmospheric Circulation over the South African Region During Austral Winter. *Journal of Climate*, 18(16), pp.3339-3355.

Reason, C.J.C. and Rouault, M. 2005. Links between the Antarctic Oscillation and Winter Rainfall over Western South Africa. *Geophysical Research Letters*, 32(7), pp.1-4.

Renaud, J. 25 January 2022. Tornado Researchers Expand Scope to Study Hail: Northern Hail Project Furthers Western's Severe Storm Investigative Strength. Available from: https://news.westernu.ca/2022/01/northern-hail-project/ [accessed 5 April 2022].

Rhome, J.R., Niyogi, D.S. and Raman, S. 2000. Mesoclimatic Analysis of Severe Weather and ENSO Interactions In North Carolina. *Geophysical Research Letters*, 27(15), pp.2269-2272.

Rigby C.A., and Steyn, A.K. 1952. The Hail Resistance of South African Roofing Materials. *South African Architectural Record*, 37(4), pp.101-107.

Rivera, J.A., Otero, F., Naranjo Tamayo, E. and Silva, M. 2020. Sixty Years of Hail Suppression Activities in Mendoza, Argentina: Uncertainties, Gaps in Knowledge and Future Perspectives. *Frontiers in Environmental Science*, 8, pp.45-50.

Robertson, S.R. 2018. The Role of Plantation Forestry for Promoting Sustainability in South Africa. *Trade and Industrial Policy Strategies*, pp.1-34.

Roos, DvdS. and Carte, A.E. 1973. The Falling Behaviour of Oblate and Spiky Hailstorms. *Journal de Recherches Atmospheriques*, 7, pp.39-62.

Roos, DvdS. 1978. Hailstone Size Inferred from Dents in Cold Rolled Aluminium Sheet. *Journal of Applied Meteorology*, 2, pp.133-138.

Roos, DvdS. 1980. Hailfall Intensities. *South African Journal of Science*, 79, pp.360-363.

Roos, DvdS. 1981. Beraming van Windspoed uit Reenmetings. *South African Weather Bureau Newsletter*, 384, pp.49-52.

Rouault, M., Pohl, B. and Penven, P. 2010. Coastal Oceanic Climate Change and Variability from 1982 to 2009 around South Africa. *African Journal of Marine Science,* 32(2), pp.237-246.

Rowan, E., Evans, C., Riley-Gilbert, M., Hyman, R., Kafalenos, R., Beucler, B., Rodehorst, B., Choate, A. and Schultz, P. 2013. Assessing the Sensitivity of Transportation Assets to Extreme Weather Events and Climate Change. *Transportation Research Record,* 2326(1), pp.16-23.

Saini, D. and Shafei, B. 2019. Prediction of Extent of Damage to Metal Roof Panels Under Hail Impact. *Engineering Structures,* 187, pp.362-371.

Santam. 16 October 2015. The Occurrence of Hail and Hail Damage in South Africa. Available from: https://www.santam.co.za/about-us/media/agriculture/the-occurence-of-hail-and-hail-damage-in-south-africa/ [accessed 15 September 2021].

Santos, J.A. and Belo-Pereira, M. 2019. A Comprehensive Analysis of Hail Events in Portugal: Climatology and Consistency with Atmospheric Circulation. *International Journal of Climatology*, 39(1), pp.188-205.

Sauer, M., Steiner, M., Sharman, R.D., Pinto, J.O. and Deierling, W.K., 2019. Tradeoffs for Routing Flights in View of Multiple Weather Hazards. *Journal of Air Transportation*, 27(2), pp.70-80.

Sawin, D., Loeper, R. and Hymes, J.L. 2023. Emergency Response to Natural Disasters the Experience of Fresenius Medical Care. *Kidney International Reports*.

Scanlon, J., Alldred, S., Farrell, A. and Prawzick, A. 1985. Coping with the Media in Disasters: Some Predictable Problems. *Public Administration Review*, 45, pp.123-133.

Schaefer, J.T., Levit, J.J., Weiss, S.J. and McCarthy, D.W. 2004. The Frequency of Large Hail over the Contiguous United States. In: *14th Conf. on Applied Climatology*, Seattle, WA, pp.1-7.

Schmidt, T.B., Unruh, L., Perino, L.J. and Montgomery, T.H. 2000. Hail Bruising of the Cattle. *The Bovine Practitioner*, pp.60-62.

Schneider, E.K., Bengtsson, L. and Hu, Z.Z. 2003. Forcing of Northern Hemisphere Climate Trends. *Journal Of the Atmospheric Sciences*, 60(12), pp.1504-1521.

Schubert, T.S. 1991. Hail Damage to Plants. Florida Department of Agriculture & Consumer Services, *Division of Plant Industry*, pp.1-2.

Seargent, D.A. 2012. Tornadoes and other Whirling Winds. In: *Weird Weather, Boston*, *Springer*, pp. 215-258.

Seneviratne, S.I., Zhang, X., Adnan, M., Badi, W., Dereczynski C., Di Lucia, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S.M., Wehner, M., and Zhou, B. 2021. Weather and Climate Extreme Events in a Changing Climate. In: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766.

Shahak, Y., Gussakovsky, E.E., Gal, E. and Ganelevin, R. 2004. Colornets: Crop Protection and Light-Quality Manipulation in One Technology. In: *VII International Symposium on Protected Cultivation in Mild Winter Climates: Production, Pest Management and Global Competition,* 659, pp. 143-151.

Shahak, Y., Ratner, K., Zur, N., Offir, Y., Matan, E., Yehezkel, H., Messika, Y., Posalski, I. and Ben-Yakir, D. 2008. Photoselective Netting: An Emerging Approach in Protected Agriculture. In: *International Symposium on Strategies Towards Sustainability of Protected Cultivation in Mild Winter Climate*, 807, pp. 79-84.

Shahak, Y., Kong, Y. and Ratner, K. 2016. The Wonders of Yellow Netting. In: *VIII International Symposium on Light in Horticulture*, 1134, pp. 327-334.

Sikhwari, T., Nethengwe, N., Sigauke, C. and Chikoore, H. 2022. Modelling of Extremely High Rainfall in Limpopo Province of South Africa. *Climate*, 10(3), p.33-39.

Sills, D.M. and Joe, P.I. 2019. From Pioneers to Practitioners: A Short History of Severe Thunderstorm Research and Forecasting in Canada. *Atmosphere-Ocean*, 57(4), pp.249-261.

Simpson, L.A. and Dyson, L.L. 2018. Severe Weather over the Highveld of South Africa During November 2016. *Water SA*, 44(1), pp.75-85.

Singh, S.K., Saxena, R., Porwal, A., Ray, N. and Ray, S.S. 2017. Assessment of Hailstorm Damage in Wheat Crop Using Remote Sensing. *Current Science*, pp.2095-2100.

Singleton, A.T. and Reason, C.J.C. 2007. Variability in the Characteristics of Cut-Off Low Pressure Systems Over Subtropical Southern Africa. In: *International Journal of Climatology: A Journal of the Royal Meteorological Society,* 27(3), pp.295-310.

Sioutas, M. 2017. Hail Characteristics and Cloud Seeding Effect for Hail Suppression in Central Macedonia, Greece. In: *Perspectives on Atmospheric Sciences*, Springer International Publishing, pp.271-277.

Smith, S.B., Reuter, G.W. and Yau, M.K. 1998. The Episodic Occurrence of Hail in Central Alberta and the Highveld of South Africa: Research Note. *Atmosphere-Ocean*, 36(2), pp.169-178.

Smith, V.H., Goodwin, B.K. and Brown, J. 2010. Private and Public Roles in Providing Agricultural Insurance in The United States. *Public Insurance and Private Markets*, pp.173-210.

Spiridonov, V., Karacostas, T., Bampzelis, D. and Pytharoulis, I. 2015. Numerical Simulation of Airborne Cloud Seeding Over Greece, Using a Convective Cloud Model. *Asia-Pacific Journal of Atmospheric Sciences*, 51, pp.11-27.

Soderholm, J.S., McGowan, H., Richter, H., Walsh, K., Weckwerth, T.M. and Coleman, M., 2017. An 18-Year Climatology of Hailstorm Trends and Related Drivers Across Southeast Queensland, Australia. *Quarterly Journal of the Royal Meteorological Society*, 143(703), pp.1123-1135.

Sood, B.R., Stockdale, G. and Rogers, E.M. 1987. How the News Media Operate in Natural Disasters. *Journal of Communication*, 37(3), 27-41.

Sowetan. 2 April 2014. How to Deal with Hail.

Stainer, C. 1977. 'Jet Set Scientists Modify Our Weather', *Rand Daily Mail,* 2 June, pp.9.

State Climate Extreme Committee. 9 December 2009. *Proposed Standards for The Collection, Storage and Measurement of Hail Stones*, pp.1-6.

Steyn, T.C. 2020. Comparing Hail Risk Management Strategies Through Whole-Farm Multi-Period Stochastic Budgeting for Avocado Production in South Africa (Doctoral Dissertation, Stellenbosch University).

Stough, S.M., Carey, L.D., Schultz, C.J. and Cecil, D.J. 2021. Examining Conditions Supporting the Development of Anomalous Charge Structures in Supercell Thunderstorms in the Southeastern United States. *Journal of Geophysical Research: Atmospheres*, 126(16), Article p.e2021JD034582.

South African Weather Service Annual Report 2017/2018. ISBN: 978-0-621-461-46138-1.

Stanger Weekly. 11 July 2018. Motor Insurance Tips. Page 14.

Stent, A. 2006. 'Ten Minutes of Icy Terror', *Daily Dispatch,* 27 December.

Sunday Independent. 19 March 2019. Big Rescue of Amur Falcons. Page 2.

Suwala, K. and Bednorz, E. 2013. Climatology of Hail in Central Europe. *Quaestiones Geographicae*, 32, pp. 99-110.

Tasin, M., Demaria, D., Ryne, C., Cesano, A., Galliano, A., Anfora, G., Ioriatti, C. and Alma, A. 2008. Effect Of Anti-Hail Nets on Cydia Pomonella Behavior in Apple Orchards. *Entomologia Experimentalis Et Applicata*, 129(1), pp.32-36.

The Citizen. 14 January 1977. Hail Claims Expected to Top R35m.

The Citizen. 24 October 2014. USA Navy Strike Stalls - The Intended Strike.

The Institute for Catastrophic Loss Reduction. 2018. Protect You Home from Hail. *ICLR's Hailsmart Program*. Canada.

The Journal. 24 October 1901. Grape Growing.

The New Age. 9 January 2015. Consumers Warned on How to Deal with Disasters. Page 17.

The Weekend Argus. 31 October 2013. Personal Finance Magazine. Page 2.

The Witness. 16 April 2010. Features. Page 13.

The Witness. 9 February 2019. Hailstorm Driving Safety Tips. Page 10.

Thiery, W., Davin, E.L., Seneviratne, S.I., Bedka, K., Lhermitte, S. and van Lipzig, N.P. 2016. Hazardous Thunderstorm Intensification Over Lake Victoria. *Nature Communications*, 7(1), Article p.12786.

Tierney, K., Bevc, C. and Kuligowski, E. 2006. Metaphors Matter: Disaster Myths, Media Frames, and their Consequences in Hurricane Katrina. *The Annals of the American Academy of Political and Social Science*, 604(1), pp.57-81.

Trenberth, K.E. and Caron, J.M. 2000. The Southern Oscillation Revisited: Sea Level Pressures, Surface Temperatures, and Precipitation. *Journal of Climate*, 13(24), pp.4358-4365.

Tshisela, N. 2010. 'Students Reap Fruit of Labour', *Sowetan,* 27 September.

Tucker, D.F. 2002. Characteristics Of Severe Hail Events in Eastern Australia. In: *21st Conference on Severe Local Storms*, pp. 12-16.

Tuovinen, J.P., Punkka, A.J., Rauhala, J., Hohti, H. and Schultz, D.M. 2009. Climatology of Severe Hail in Finland: 1930–2006. *Monthly Weather Review*, 137(7), pp.2238-2249.

Tuovinen, J.P., Jokinen, P. and Schultz, D.M. 2018. Historical Hail Cases in Finland: 1776-1910. *Boreal Environment Research*, 23, pp.29-57.

Tyson, P.D. 1986. Climate Change and Variability in Southern Africa. Oxford University Press, Cape Town.

Tyson, P.D. and Preston-Whyte, R.A., 2000. Weather And Climate of Southern Africa. Oxford University Press.

Umraw, A. 2015. 'Storm's Trail of Damage - Hailstorm Leaves…',*The Witness,* 9 February, pp.3.

UNISDR. 2009. 2009 UNISDR Terminology on Disaster Risk Reduction. *United Nations Office on Disaster Risk Reduction*, Geneva.

Urdiroz, A. 2017. Managing Hailstorms. Safety First – 4 June 2017. Available from: https://safetyfirst.airbus.com/app/themes/mh_newsdesk/documents/archives/managing-hailstorms.pdf [accessed 15 June 2022].

Van Graan, R. 1977. 'Hail Damage Claims Soar to R23m', *The Citizen,* 12 January.

Vasterman, P., Yzermans, C.J. and Dirkzwager, A.J. 2005. The Role of the Media and Media Hypes in the Aftermath of Disasters. *Epidemiologic Reviews*, 27(1), pp.107-114.

Vigaud, N., Richard, Y., Rouault, M. and Fauchereau, N. 2009. Moisture Transport between the South Atlantic Ocean and Southern Africa: Relationships with Summer Rainfall and Associated Dynamics. *Climate Dynamics*, 32(1), pp.113-123.

Vista. 24 March 2011. *C*heck Your Roof Before the Rainy Season*.* Page 33.

Visser, P.J. and Van Heerden, J. 2000. Comparisons of Hail Kinetic Energy Derived from Radar Reflectivity with Crop Damage Reports Over the Eastern Free State. *Water SA-Pretoria,* 26(1), pp.91-96.

Walters, G., Mair, J. and Lim, J. 2016. Sensationalist Media Reporting of Disastrous Events: Implications for Tourism. *Journal of Hospitality and Tourism Management*, 28, pp.3-10.

Watkins, M.D. and Bazerman, M.H. 2003. Predictable Surprises: The Disasters You Should Have Seen Coming. *Harvard Business Review*, 81(3), pp.72-85.

Webb, L.B., Whetton, P.H. and Barlow, E.W.R. 2008. Climate Change and Winegrape Quality in Australia. *Climate Research*, 36(2), pp.99-111.

Weber, E.J., 2019. Weather Index Insurance in Sub-Saharan Africa. Available at SSRN 3396489.

West, E. 2016. 'Avocado Production Takes a Hit', *The Witness*, 19 October, pp.10.

Widmer, A. 2000. Light intensity and fruit quality under hail protection nets. In: *VII International Symposium on Orchard and Plantation* Systems, 557, pp. 421-426.

Wieringa, J. and Holleman, I. 2006. If Cannons Cannot Fight Hail, What Else? *Meteorologische Zeitschrift*, 15(6), pp.659-670.

Wildenboer, N. 2013. *Diamond Fields Advertiser,* 6 December, pp.13.

Wouters, A., Boon, M., van Putten, D., van't Veen, B., Koks, E. and de Moel, H. 2019. A Hail Climatology of the Netherlands. *EIT Climate - KIC*, pp.1-37.

Wright, C.Y., Dominick, F., Kapwata, T., Bidassey-Manilal, S., Engelbrecht, J.C., Stich, H., Mathee, A. and Matooane, M. 2019. Socio-Economic, Infrastructural and Health-Related Risk Factors Associated with Adverse Heat-Health Effects Reportedly Experienced During Hot Weather in South Africa. *The Pan African Medical Journal,* 34, pp.40-49.

Wu, W. 2015. Research On Various Building Materials for Structural Components. *International Conference on Civil, Materials and Environmental Sciences* (CMES2015), pp.480-491.

Wunsch, M.S. and French, M.M. 2020. Delayed Tornadogenesis Within New York State Severe Storms. *Journal of Operational Meteorology*, 8(6), pp.79-92.

Xulu, N.G., Chikoore, H., Bopape, M.J.M. and Nethengwe, N.S. 2020. Climatology Of the Mascarene High and Its Influence on Weather and Climate Over Southern Africa. *Climate*, 8(7), pp.86-96.

Yang, S., Shu, K., Wang, S., Gu, R., Wu, F. and Liu, H. 2019. Unsupervised Fake News Detection on Social Media: A Generative Approach. In: *Proceedings of The AAAI Conference on Artificial Intelligence*, 33(1), pp. 5644-5651.

Yoga, S. and Vetrivel, K. 2012. Origin and Progress of Crop Insurance in India- A Historical View. *Review of Research*, 1, pp.1-4.

Young, F.R., Apan, A. and Chandler, O. 2004. Crop Hail Damage: Insurance Loss Assessment Using Remote Sensing. *Mapping And Resource Management: Proceedings of RSPSoc2004*.

Yue Y, Zhou L, Zhu A-x, Ye X. 2019. Vulnerability of Cotton Subjected to Hail Damage. *PLoS ONE*, 14(1), Article e0210787. Available from: https://doi.org/10.1371/journal.pone.0210787 [accessed 29 June 2022].

Zankowski, J., Sun, Y., Poon, C., Passauer, E., Nassar, A. and Mehta, K. 2013. Gutter Design and Selection for Roof Rainwater Catchment Systems. In: *2013 IEEE Global Humanitarian Technology Conference (GHTC)*, pp. 226-231.

Zhao, J.L., Zhang, D.Y., Luo, J.H., Huang, S.L., Dong, Y.Y. and Huang, W.J. 2012. Detection and Mapping of Hail Damage to Corn Using Domestic Remotely Sensed Data in China. *Australian Journal of Crop Science*, 6(1), pp.101-108.

Zhou, J., Pavek, M.J., Shelton, S.C., Holden, Z.J. and Sankaran, S. 2016. Aerial Multispectral Imaging for Crop Hail Damage Assessment in Potato. *Computers and Electronics in Agriculture*, 127, pp.406-412.

Zuber, K., Hall, C., Murphy, P. and Evans, D. 2013. Enhanced Abrasion Resistance of Ultrathin Reflective Coatings on Polymeric Substrates: An Improvement Upon Glass Substrates. *Wear*, 297(1-2), pp.986-991.

20 Years of Bohle in South Africa, n.d. Available from: https://www.bohle.com/en-za/company/history/20-years-bohle-south-africa/ [accessed 10 June 2022].

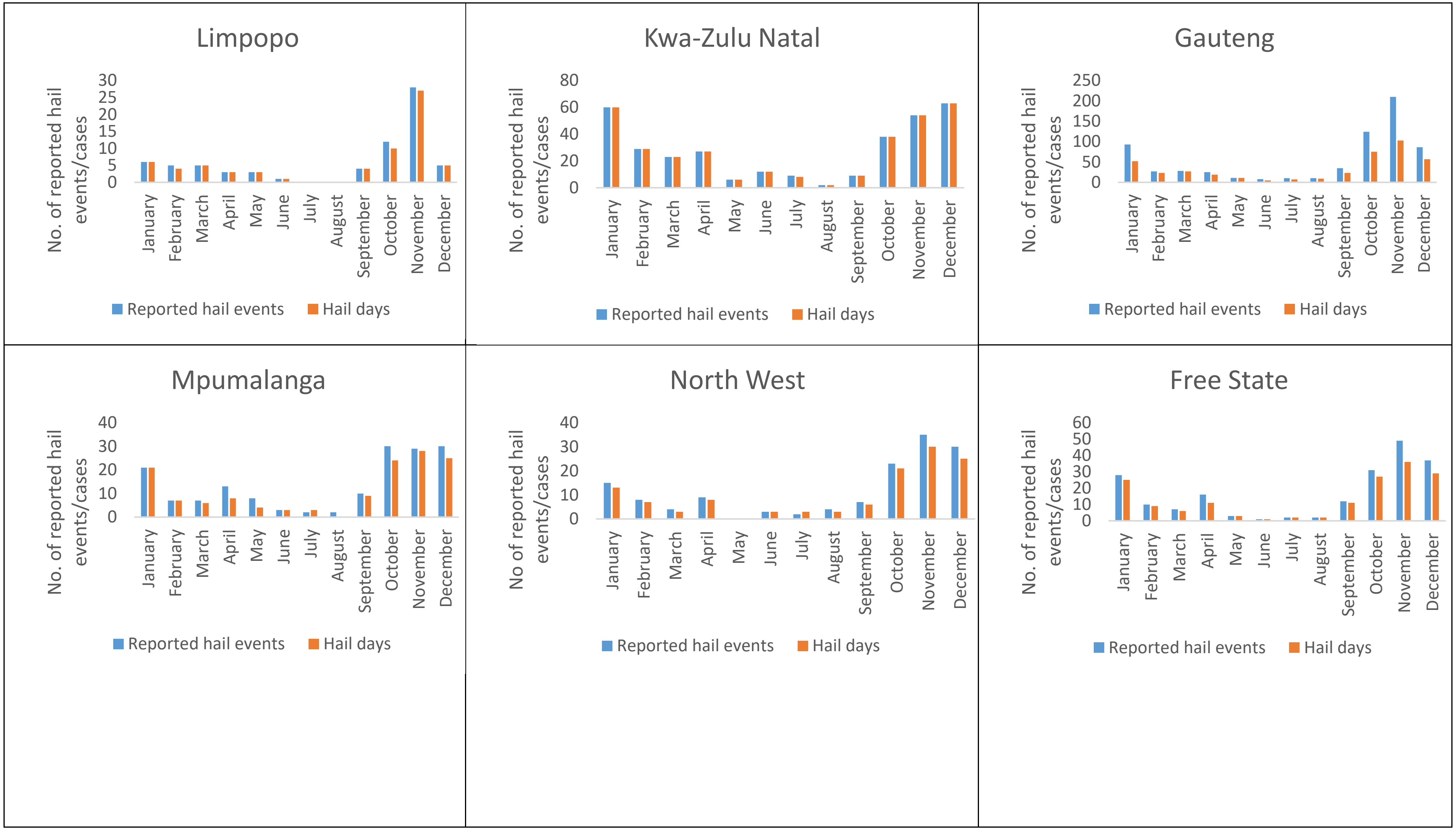
APPENDICES

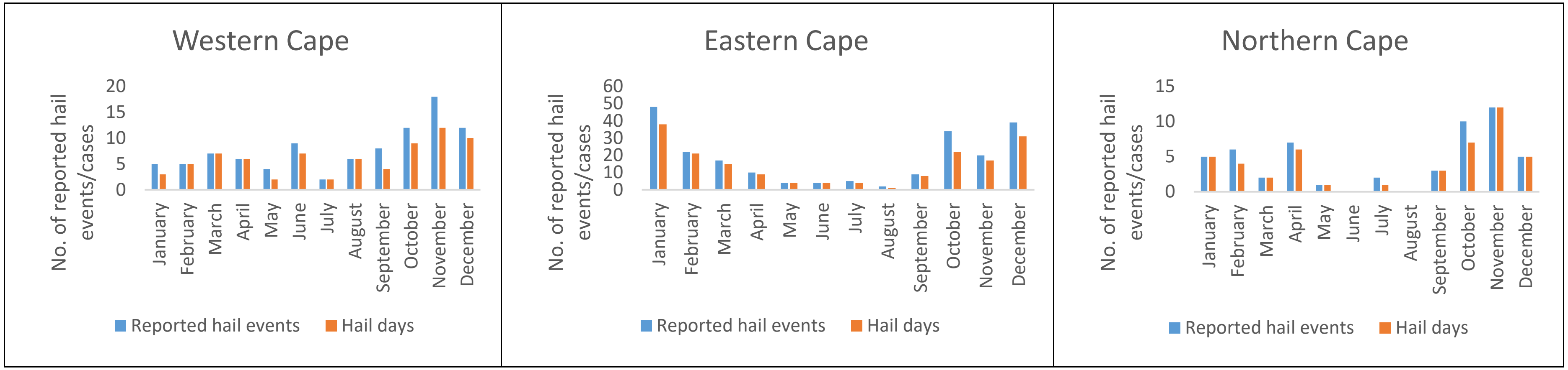
Appendix 1 ..\Masters Newspaper pages with hail\Hail - newspaper data. 1900-2019.xlsx

Appendix 2: *Wind speed values associated with newspaper reported hail events.*

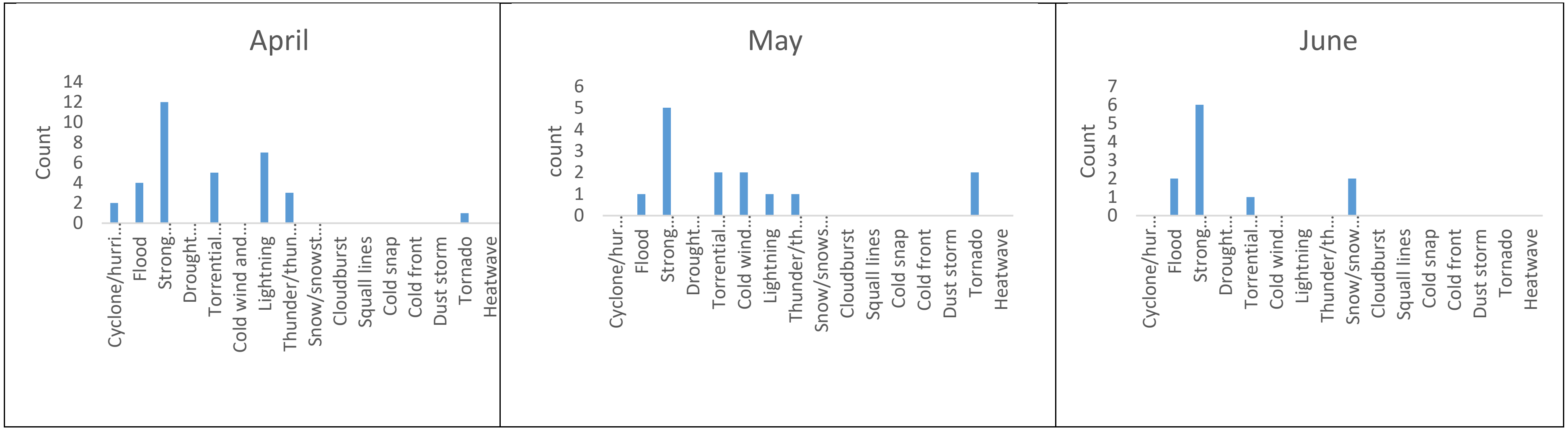
Publication	Date of publication (and hail event)	Wind speed	Confluence	Hailstone size
Rand Daily Mail	6 November 1914 (5 November 1914)	70mph (112.65km/h)	Berea, Parktown and northern suburbs (Gauteng)	
Rand Daily Mail	10 November 1930 (8 November 1930)	60-70mph (96.56-112.65km/h)		Hen's eggs
Rand Daily Mail	23 April 1934 (22 April 1934)	60mph (96.56km/h)	Thornville to Avoca (KZN)	
Rand Daily Mail	18 November 1836 (1 November 1936)	90mph (144.84km/h)	Maluti Mountains (Harrismith) (KZN)	
Rand Daily Mail	26 November 1940 (22 November 1940)	80 mph (128.74km/h)	Pietersburg (Limpopo)	
Rand Daily Mail	11 December 1952 (10 December 1952)	96.56km/h	Mazelspoort (Free State)	
Rand Daily mail	10 December 1960 (8 December 1960)	70mph (112.65km/h)	Estcourt (KZN)	
Rand Daily Mail	27 April 1981 (26 April 1980)	45 knots (83.34km/h)	Johannesburg, Krugersdorp (Gauteng)	
Rand Daily Mail	11 December 1982 (10 December 1982)	42 knots (77.78 km/h)	Johannesburg (Gauteng)	
Weekend Argus	30 July 1993 (29 July 1993)	25 knots (46.3km/h)	Durban North, Phoenix, Chatsworth, Umhlanga and Avoca (KZN)	
Die Volksbald	24 April 1999 (22 April 1999)	120km/h	Lanseria (Gauteng)	Golf balls
Business Day	14 September 2001 (12 September 2001)	90km/h	Midrand, Tembisa, Ivory Park (Gauteng)	
Sunday Times	27 January 2006 (25 January 2006)	90 km/h	Elliot (Eastern Cape)	Tennis balls/man's fist
The Herald	28 December 2006 (26 December 2006)	120km/h	Indwe (Eastern Cape)	Eggs
Sowetan	8 January 2013 (6 January 2013)	104km/h	Pietermaritzburg, Copesville (KZN)	
The Witness	26 February 2014 (24 February 2014)	180km/h	Pietermaritzburg (KZN)	Golf balls
The Rep	18 October 2014 (16 October 2014)	65km/h	Trompsburg and Jagersfontein (Free State)	

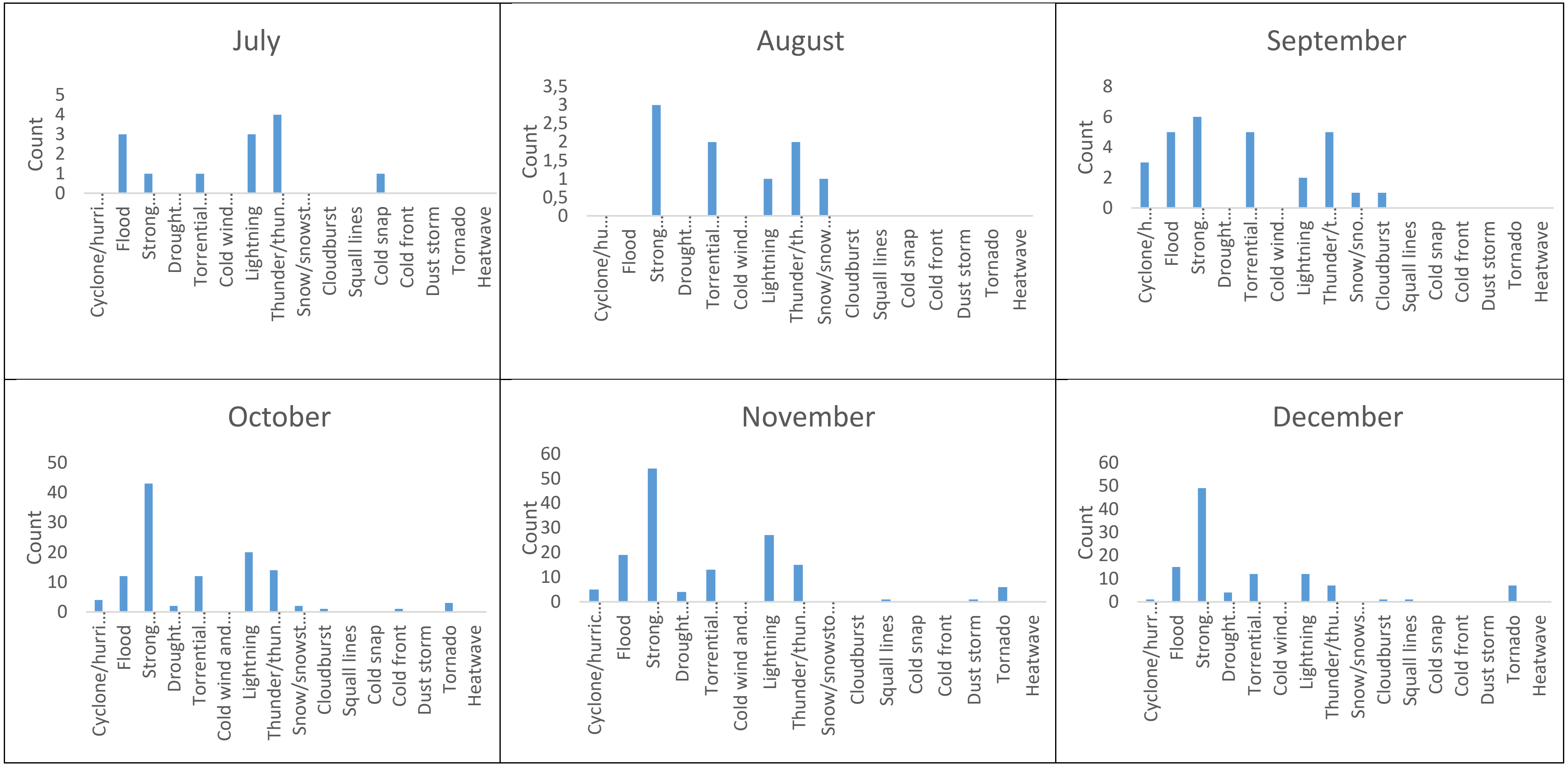
Appendix 3: *Monthly distribution of hail events and hail days per province from 1900-2019.*



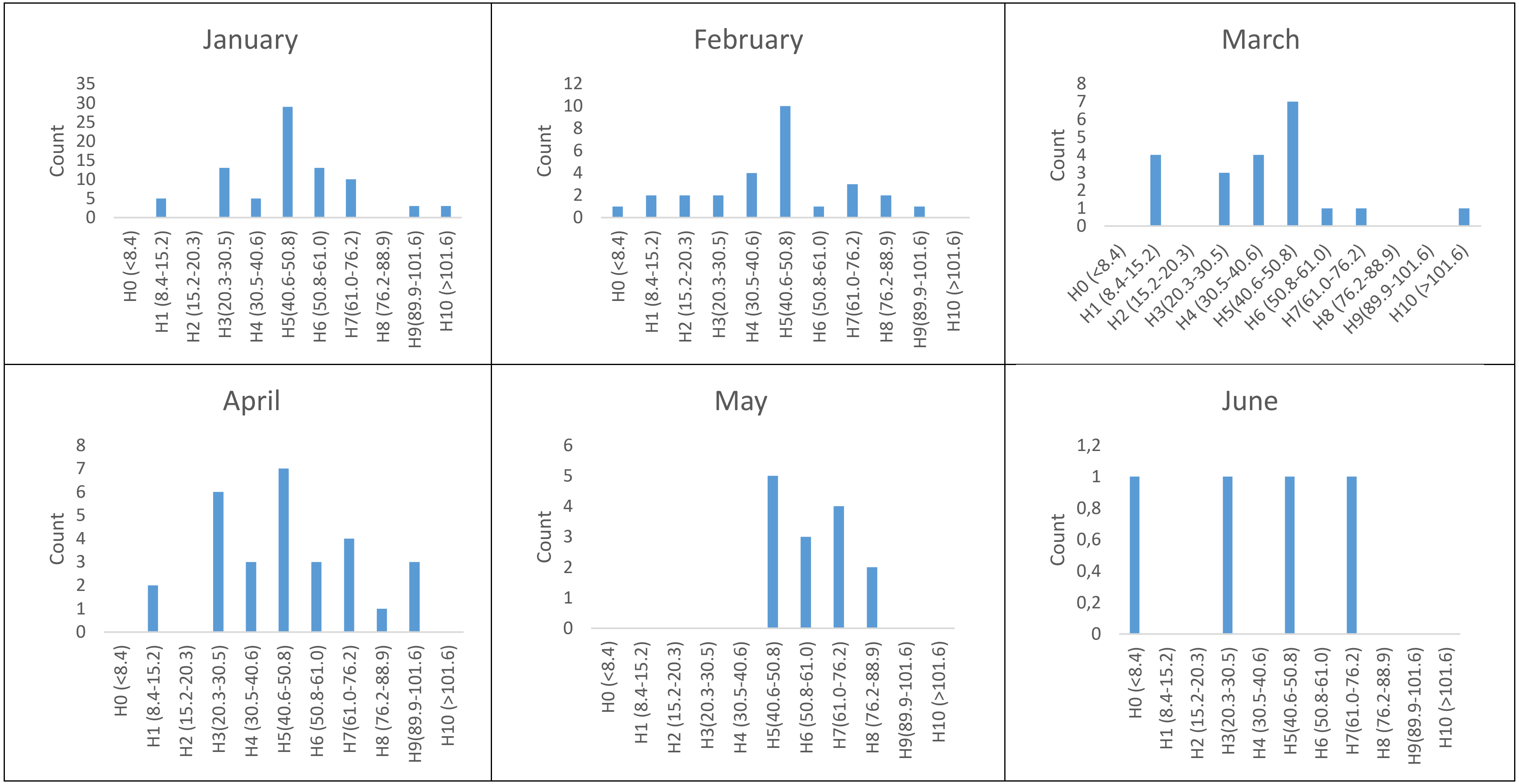


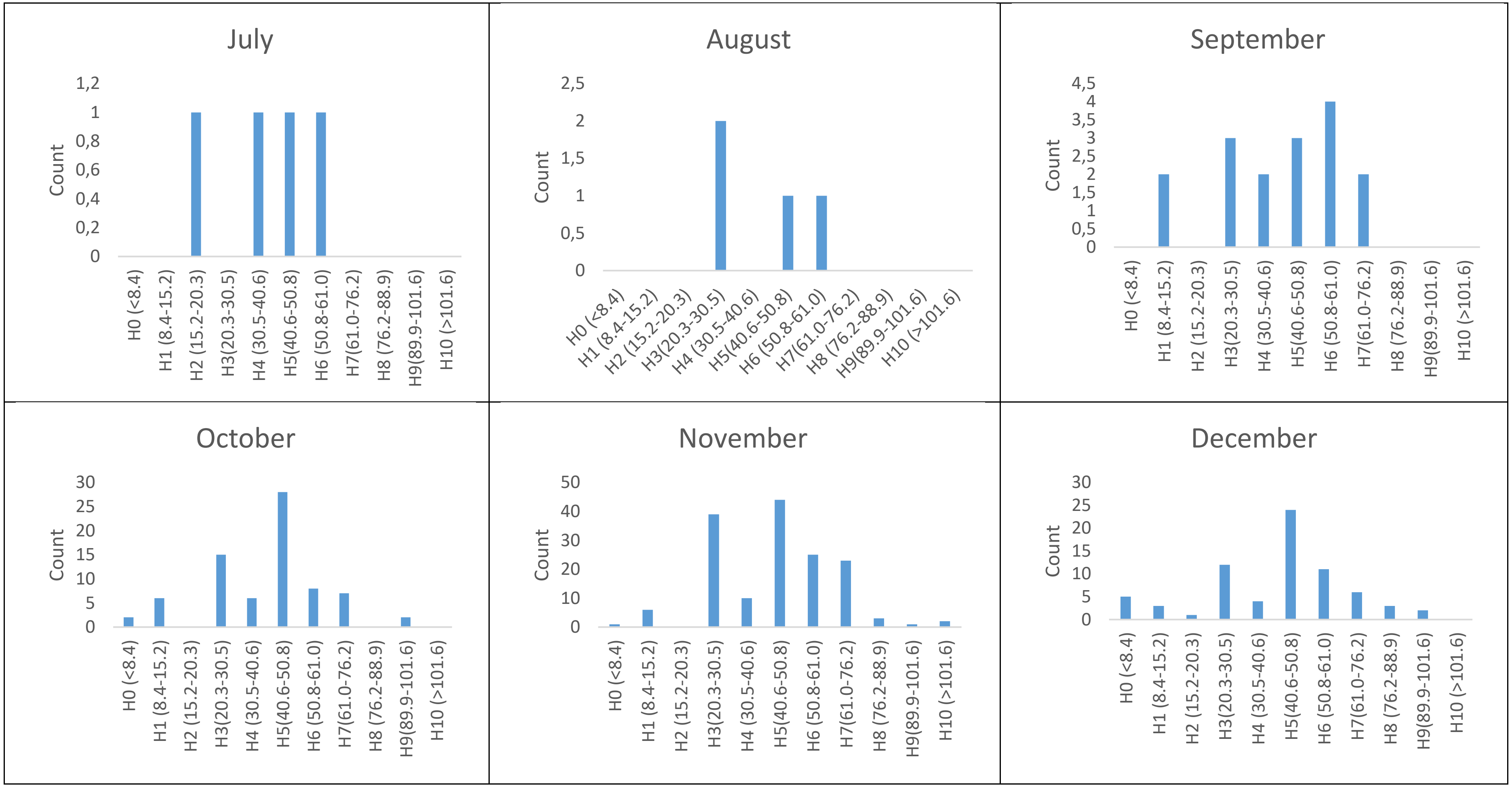
Appendix 4: *Monthly occurrence of weather-related events that there reported to accompany hail/hailstorm in newspapers from 1900-2019.*




July
Count
5
4
3
2
1
0
Cyclone/hurri…
Flood
Strong…
Drought…
Torrential…
Cold wind…
Lightning
Thunder/thun…
Snow/snowst…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave
August
Count
3,5
3
2,5
2
1,5
1
0,5
0
Cyclone/hu…
Flood
Strong…
Drought…
Torrential…
Cold wind…
Lightning
Thunder/th…
Snow/snow…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave
September
Count
8
6
4
2
0
Cyclone/h…
Flood
Strong…
Drought…
Torrential…
Cold wind…
Lightning
Thunder/t…
Snow/sno…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave
October
Count
50
40
30
20
10
0
Cyclone/hurri…
Flood
Strong…
Drought…
Torrential…
Cold wind and…
Lightning
Thunder/thun…
Snow/snowst…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave
November
Count
60
50
40
30
20
10
0
Cyclone/hurric…
Flood
Strong…
Drought…
Torrential…
Cold wind and…
Lightning
Thunder/thun…
Snow/snowsto…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave
December
Count
60
50
40
30
20
10
0
Cyclone/hurr…
Flood
Strong…
Drought…
Torrential…
Cold wind…
Lightning
Thunder/thu…
Snow/snows…
Cloudburst
Squall lines
Cold snap
Cold front
Dust storm
Tornado
Heatwave

Appendix 5: *Monthly distribution count of hailstone size and relative damage type after Bal et al. (2014).*




July
Count
1,2
1
0,8
0,6
0,4
0,2
0
August
Count
2,5
2
1,5
1
0,5
0
September
Count
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
October
Count
30
25
20
15
10
5
0
November
Count
50
40
30
20
10
0
December
Count
30
25
20
15
10
5
0
H0 (<8.4)
H1 (8.4-15.2)
H2 (15.2-20.3)
H3(20.3-30.5)
H4 (30.5-40.6)
H5(40.6-50.8)
H6 (50.8-61.0)
H7(61.0-76.2)
H8 (76.2-88.9)
H9(89.9-101.6)
H10 (>101.6)

Appendix 6: *Monthly count of hailstone sizes reported in newspaper events from 1900-2019 in 20-year intervals*