SEVERE CONVECTIVE STORM RISK IN THE EASTERN CAPE PROVINCE OF SOUTH AFRICA

A thesis submitted in fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
of
RHODES UNIVERSITY

by

DESMOND MARK PYLE

November 2006

ABSTRACT

This study investigates the temporal, spatial and impact characteristics of severe convective storm hazard and risk in the Eastern Cape Province of South Africa. Using historical data on severe convective storms dating from 1897, patterns of the hazard threat and risk to various geographic populations were investigated. A conceptual framework that emphasises the combined role hazard and vulnerability play in defining risk was used for the study. A methodology for ranking the severity of the storms in the historical dataset, based on recorded damage/impact, was specifically developed for the study. It is intended that this methodology will have a potentially wider application and may be adapted to a range of hazard impact and risk studies in South Africa and internationally. The study was undertaken within the context of the South African Disaster Management Act of 2002. Findings of the study show that severe convective storms can occur throughout the province, but there are clearly demarcated areas of higher frequency and concentration. The impact of storms is particularly severe on impoverished and vulnerable rural populations in the eastern parts of the province, where there is an urgent need for building capacity in disaster risk management. A major outcome of the study is the production of a severe convective storm hazard/risk map of the Eastern Cape, which it is hoped will be of benefit to a number of stakeholders in the province, particularly disaster management, but also the South African Weather Service, agricultural organisations, development/planning authorities, educational authorities and risk insurers. It is hoped that this map and the study in general will assist in guiding the operational responses of the various authorities, especially in terms of those interventions aimed at disaster risk reduction in the Eastern Cape.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor, Professor Kate Rowntree, for her support, advice and encouragement while completing this thesis.

I am deeply grateful to the following persons who have also provided invaluable support and assistance during the past number of years:

Dr Shamsuddin Shahid for GIS assistance (Figures 14-18; 25-29; 32-34; 36; 40-57).

Mrs Susan Abraham for assistance in preparing the diagrams in this thesis (Figures 1-11; 13).

Professor Etienne Nel for helpful comments and unfailing encouragement.

Dr Matthew Gibb for assistance with the final editing and layout of this thesis.

Ms Lisl Griffioen for proofreading this thesis.

Mr Hugh van Niekerk and Mr Garth Sampson for climate information and technical advice from the South African Weather Service in Port Elizabeth.

Finally, to my wife, Sue and my children, Andrew, Michael and Serena, who have endured many years of my research and writing with great forbearance. I would not have been able to complete this thesis without their selfless support and encouragement; this thesis is as much theirs as it is mine.

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

ACRONYMS

ACDS	African Centre for Disaster Studies
BRN	Bulk Richardson Number
CAPE	Convective Available Potential Energy
CSIR	Council for Scientific and Industrial Research
DiMP	Disaster Mitigation for Sustainable Livelihoods Programme
DRI	Disaster Risk Index
DMA	Disaster Management Act
ECSS	European Conference on Severe Storms
FPP	Fujita-Pearson Scale
GIS	Geographical Information Systems
HDI	Human Development Index
IADB	Inter-American Development Bank
IDP	Integrated Development Plan
IDNDR	International Decade for Natural Disaster Reduction
ISDR	International Strategy for Disaster Reduction
LDN	Lightning Detection Network
LI	Lifted Index
MCC	Mesoscale Convective Complex
MCS	Mesoscale Convective System
MSG	Meteosat 8 or Meteosat Second Generation
NDMC	National Disaster Management Centre
NDMF	National Disaster Management Framework
NMMM	Nelson Mandela Metropolitan Municipality
NSSL	National Severe Storms Laboratory
NOAA	National Oceanic & Atmospheric Administration
NWS	National Weather Service
PAR	Pressure and Release
pers. comm.	Personal Communication
PRA	Participatory Rural Appraisal
RSA	Republic of South Africa
SAWS	South African Weather Service

SSTs	Sea Surface Temperatures
SI	Showalter Index
SRH	Storm Relative Helicity
TORRO	Tornado and Storm Research Organisation
TS	Thunderstorm Severity
TS1	Moderate Storm
TS2	Significant Storm
TS3	Severe Storm
TS4	Very Severe Storm
TS5	Devastating Storm
UNDP	United Nations Development Programme
USA	United States of America

CHAPTER ONE: INTRODUCTION

> *There's a sense of dread in Umtata when a particular kind of storm develops: the sky turns black, the wind howls, and the rain pelts down. The people who live there swear they can tell a tornado is on the way – and they pray they are not in its path.*
>
> Bennett, 1999; 18

1.1 Background to the study

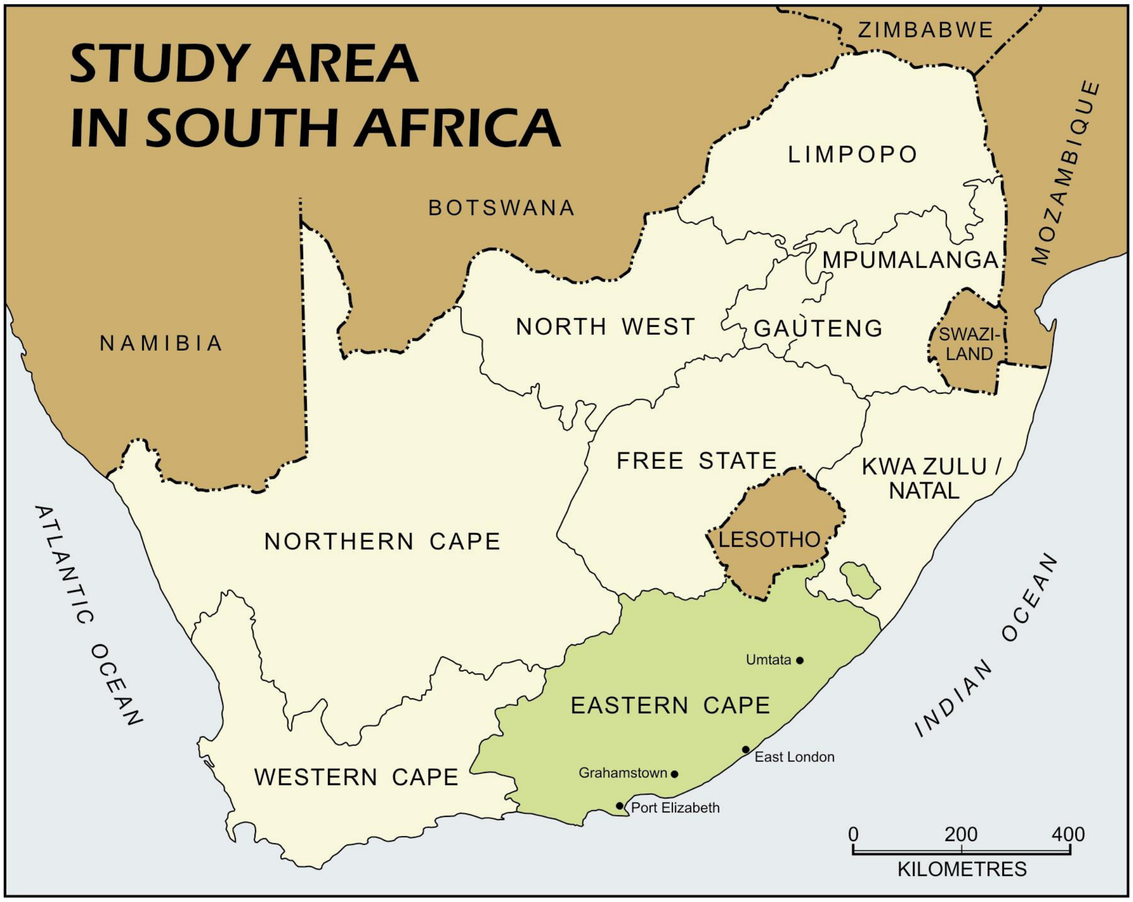
Severe convective storms are recognised as exceptionally powerful and destructive meteorological events which result in both death and loss of property, as well as livelihood in many parts of the world. The frequency and magnitude of severe weather events such as tropical cyclones, hailstorms, droughts and floods appears to be on the increase globally. This trend has been ascribed, in part, to anthropogenic climate change but also and, perhaps more importantly, to rapidly increasing human vulnerability to climate and other natural hazards (Jones, 1991; Blaikie *et al.*, 1994; Tobin and Montz, 1997; Loster, 1999; Jackson, 2000). Weather-related natural catastrophes (windstorms and floods), on average, account for more than 70% of all insured economic losses. It is significant that excluded from global statistics on disasters and catastrophes are the almost unnoticed, unspectacular localised disasters in the less developed parts of the world which, although they do not make international news, are devastating for small communities in terms of loss of income and livelihoods (Schmidlin and Ono, 1996; Karimanzira, 1999; Republic of South Africa [RSA], 1999). The relative burden exerted by disasters is at its highest in countries with low per-capita income (Munich Reinsurance, 2000; Red Cross/Red Crescent Climate Centre, 2005). Forecasts for the future are congruent with current trends; most scientists warn of an increasing frequency and severity of natural disasters (in particular those that are weather and climate-related) on a global and local scale (Berz, 2000; Jackson, 2000; Loster, 2000; Vellinga and van Verseveld, 2000). In line with global trends, southern Africa can expect to be affected by a greater frequency and severity of floods and droughts and other extreme weather events in the future (Karimanzira, 1999; Hewitson, 2006). The increasing vulnerability of marginalised, poverty-stricken communities in southern Africa is likely to exacerbate the situation even further (RSA, 1999; Houghton, 2004).

1.2 Problem identification/definition

Severe storms in the Eastern Cape are a more frequent and severe phenomenon than has been reported in the past, and pose a significant risk for various geographic populations in terms of loss of life, injury and impact on livelihoods. Historical under-reporting of storms has resulted in an under-emphasis of the significant impact on marginalised and highly vulnerable rural populations. Significantly, the Eastern Cape is characterised by very high levels of socio-economic deprivation; this is particularly apparent in the eastern parts of the province that contain the former homeland areas of the Ciskei and the Transkei. A very clear west-east divide with respect to relative wealth and poverty characterises the province, where the western areas are noticeably wealthier and better developed than the predominantly rural eastern areas. Past research in this country has focused on tornadoes and other weather hazards, such as floods and droughts. In spite of the severe risk posed by storms in South Africa, to the researcher's knowledge no rigorous, scientific research has been undertaken yet on the suite of severe thunderstorm hazards from a multi-hazard perspective: damaging winds, hail, lightning and flash flooding. In addition, the Disaster Management Act of 2002 stipulates that hazard and risk assessment must be undertaken at local, provincial and national scale (RSA, 2002); no scientific, rigorous assessment of severe storm hazard has been undertaken yet in the Eastern Cape. These factors provide the major rationale for undertaking this study on severe storm risk in the Eastern Cape.

The study area is shown in Figure 1. It was decided to include storm events which had occurred in the Kokstad/Matatiele area of southern KwaZulu-Natal. This area forms a narrow corridor between the two municipal areas of Umzimvubu and Umzimkulu of Alfred Nzo District Municipality in the extreme north-eastern Eastern Cape (*vide* Figure 14 in Chapter 7). The researcher asserts that by including storm events in the Kokstad/Matatiele area, a more accurate indication of storm distribution for the whole north-eastern region will be provided. Changes to the border between the Eastern Cape and KwaZulu-Natal in this contested area have been effected very recently, but for this thesis the pre-2006 borders have been used as the researcher is of the opinion that they may well be re-aligned again in the future.

Figure 1 Map of the study area



1.3 Purpose, goals and objectives of the study

1.3.1 Purpose

To investigate the extent and impact of severe storms in the Eastern Cape and to make recommendations concerning mitigation, early warning and effective disaster risk management and planning in the province.

1.3.2 Goals/broad objectives

- To document severe storm incidence and impact in the Eastern Cape over the period of available record.

- To assess the risk of severe storm hazard to various geographic populations in the Eastern Cape.
- To make recommendations concerning effective disaster management and planning in the Eastern Cape, in line with recommendations contained in the Disaster Management Act of 2002 and the National Disaster Management Framework (NDMF) of 2005.

1.3.3 Objectives

- To document, map and analyse severe storm incidence in the Eastern Cape over the period of available record
- To assess the intensity and spatial extent of severe storm hazard in the Eastern Cape, with particular reference to the rural areas of the former Transkei and Ciskei
- To assess the vulnerability of various geographic populations to severe storms in the Eastern Cape
- To assess the risk of various geographic populations to severe storms in the Eastern Cape
- To evaluate disaster risk management structures and developments in the Eastern Cape, in relation to the Disaster Management Act of 2002
- To make recommendations concerning effective disaster risk management in the Eastern Cape, in relation to the Disaster Management Act of 2002
- To provide a broad base on which further research in this field can be conducted in more local contexts

1.4 Limitations to the study

- The researcher acknowledges that whilst a meticulous approach was adopted to obtaining reports of severe storms from a wide range of sources, some events may have been missed. In addition, given the sporadic nature of reporting in the past, not all events which have actually occurred will have been recorded in this study. As a result, the database on severe storm occurrences, as opposed to reported events, is incomplete.

- Local variations and nuances in storm hazard, vulnerability and risk will not be captured in any detail, given the larger municipal and district scale used in this study.
- The indicators chosen to express vulnerability focus on socio-economic and physical/infrastructural factors. The role of institutional factors and mechanisms in affecting vulnerability has not been included in this analysis but future research could include this additional complexity.

1.5 Conceptual framework

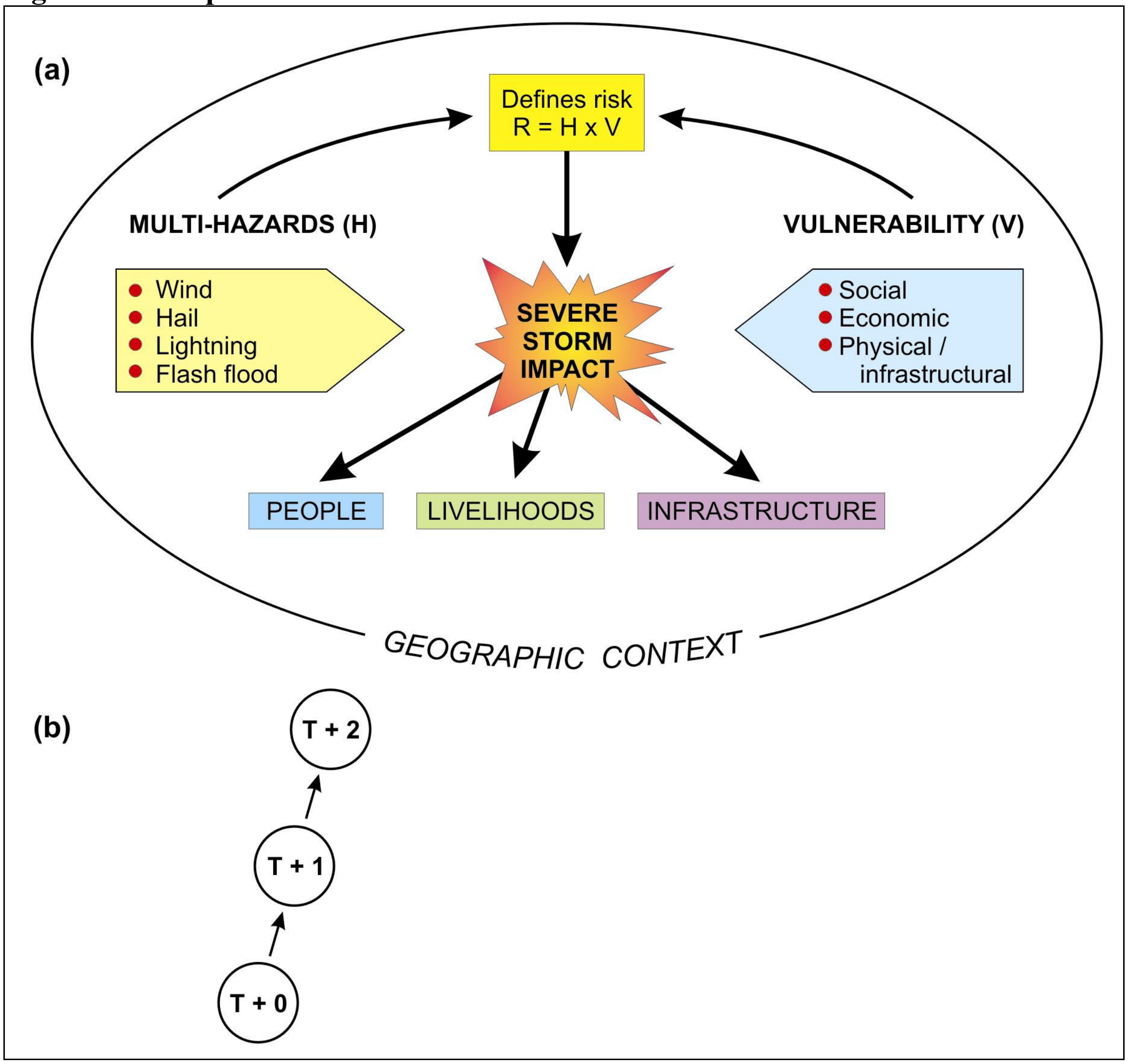
A conceptual framework emphasising the interplay of hazard and vulnerability in defining risk has been used in this study. Whilst authors have proposed various models to examine hazard, vulnerability and risk, a common feature of recent conceptual frameworks is the realisation that disasters or hazard impacts arise from a combination of hazard and vulnerability. A hazard is not the single causal agent, rather it is viewed as a "trigger" which sets off a disaster. Risk is therefore seen as the product of both hazard and vulnerability, according to the equation R = H x V. Using this conceptualisation, hazard in this study is understood to be a severe convective storm, whilst vulnerability refers to the underlying socio-economic and physical/infrastructural conditions, which may ameliorate or aggravate storm impacts. Risk is understood to be the likelihood of loss as product of both hazard impact and vulnerability.

Whilst Blaikie *et al.'s* (1994) Pressure and Release (PAR) Model and Access Model stress the social causation of disasters, Cutter's (1996) hazards of place model of vulnerability explicitly focuses on the importance of geographic locality in defining risk and vulnerability. These models are discussed further in Chapter Two. In seeking to find a balance between the two models, a framework (Figure 2) was developed for this study by adapting and expanding the ideas of both Blaikie *et al.* (1994) and Cutter (1996). Importantly, this study focuses not only on large-scale disasters but also on the frequently recurring, small-scale events which may accumulate into substantial losses for communities in impoverished areas (International Strategy for Disaster Reduction [ISDR], 2004; United Nations Development Programme [UNDP], 2004).

The conceptual framework developed for this study is simple, yet it embraces four vital aspects of severe storm risk, *viz.*

- risk is the product of storm hazard and vulnerability
- risk is often compounded by the multi-hazard nature of severe storms
- higher risk is associated with greater impact and losses
- risk has a geographic context (located in time and space) and is dynamic

Figure 2 Conceptual framework: A multi-hazard model of severe storm risk



Adapted from Blaikie *et al.* (1994; 23) and Cutter (1996; 536)

Figure 2 (a) emphasises the importance of the geographic context of hazard, vulnerability and risk, while Figure 2 (b) stresses the dynamic aspect of risk, i.e. as hazard and vulnerability change with time, so does risk.

Borrowing from the ideas of Cutter (1993; 8-9), this study uses a scientifically robust, eclectic approach "employing a wide range of approaches: spatial, contextual, historical, narrative and quantitative…allowing for comparisons and a fuller understanding of the causes and consequences of hazard". The epistemological stance adopted in this study is logical-empirical.

1.6 The structure of the study

Chapter Two discusses the key conceptual issues and debates surrounding natural hazards, disasters and risk within the context of escalating impacts on a local and global scale.

Chapter Three provides a critical review of current thinking on climate hazards. Furthermore empirical studies, methodologies and conceptual frameworks relevant to this study, both local and international, are critically evaluated.

Chapter Four critically evaluates developments in disaster risk management as a vital component in mitigating risk, internationally, nationally and locally.

Chapter Five provides a critical review of approaches and methods proposed for assessing hazard, vulnerability and risk.

Chapter Six sets out the research methods and procedures applied in this study, based on the reviews of methodological and conceptual frameworks in Chapter Three and Chapter Five.

Chapter Seven provides an analysis of the physical dimensions of severe storm hazard and associated impacts in the Eastern Cape.

Chapter Eight provides an analysis of the pattern of vulnerability to severe storms in the Eastern Cape.

Chapter Nine provides an analysis of the pattern of risk to severe storms in the Eastern Cape.

Chapter Ten presents the conclusions and recommendations arising from the study.

CHAPTER TWO: NATURAL HAZARDS, DISASTERS AND RISK

> *Yet, in many parts of Africa…every day is accompanied by significant natural and manmade dangers.*
>
> Holloway, 1999; 207

2.1 Introduction

The purpose of this chapter is to provide the international and national context in which this study was undertaken, with reference to natural hazards, disasters and risk. Key definitions are provided in order to clarify the main concepts within the hazards and disaster field.

2.2 The impact of natural hazards and disasters

On a global level, the impact of natural hazards and disasters is staggering. The International Strategy for Disaster Reduction provides a sobering perspective:

"Every year, more than 200 million people are affected by droughts, floods, cyclones, earthquakes, wildfires and other hazards. Increased population densities, environmental degradation and global warming make the impacts of natural hazards worse…the past few years have reminded us that natural hazards can affect anyone, anywhere…hundreds of thousands of people have lost their lives, and millions their livelihoods, to disasters caused by natural hazards" (ISDR, 2005; 1)

The Third Assessment Report of the Intergovernmental Panel on Climate Change predicts, with a high level of confidence, an increasing frequency and intensity of extreme weather events in the 21st Century (Houghton *et al.,* 2001). People in the least developed countries are most likely to be affected; at a community level the poorest and most vulnerable groups are most at risk, particularly women, children, the elderly and the disabled (Red Cross/Red Crescent Climate Centre, 2005).

In Africa, and particularly southern Africa, the major natural hazards are climate- and weather-related, in line with global patterns. Floods and droughts exact the highest toll on human and economic life (RSA, 1994 ; RSA 1999). The floods in southern Africa in February 2000, which devastated areas of Mozambique, Zimbabwe, Botswana and South Africa, have been listed as the worst global natural disaster of 2000. Approximately half a million people were left homeless and five million were affected by the floods (Berz, 2000). Protracted droughts persist in many parts of Africa, yet other areas have recently suffered from devastating floods since July 2006, in particular the east African countries of Ethiopia, Sudan, Eritrea, Somalia, Kenya and Uganda. The United Nations reports that nearly 1 000 people had died and more than 100 000 had been displaced as a result of the heavy flooding (Sapa-AFP, 2006). In August of 2006 large-scale flooding causing many millions of Rands in damages in the Western Cape and the Eastern Cape provinces of South Africa; this has served as a timely reminder that this country is very vulnerable to recurrent episodes of flooding.

2.3 Natural hazards, disasters and risk: theoretical and conceptual frameworks and models

Smith (1992) asserts that scientific interest in natural hazards is of fairly recent origin. The traditional view saw natural hazards and disasters as "Acts of God" whereby destruction has been attributed to the extremes of nature. According to Tobin and Montz (1997) the physical world was seen by theorists during the earlier part of the 20th Century as an external force, separate from human forces. Investigations focused almost exclusively on the physical causes and behaviour of particular extreme events (White, 1974; Hewitt, 1997).The focus changed, however, due in part to a need for physical geographers to make their work more relevant to human affairs, and the 1970s witnessed a number of seminal works on natural hazards and disasters produced by White (1974), White and Haas (1975) and Burton *et al.* (1978) emphasising the human use system and adopting a people-environment approach (Smith, 1992). According to the approach of researchers in the 1970s, hazards occur at the interface between the natural processes of the environment and people seeking a living through their use of the earth and its natural resources (Smith, 1992). Blaikie *et al.* (1994; 4) describe this approach as "subtle environmental determinism" in which the limits of human rationality and consequent misperception of nature lead to tragic misjudgements.

By the end of the 1970s a more human explanation of hazards was evolving and in some instances physical processes were almost eliminated (Tobin and Montz, 1997). Hewitt (1997) explains that disaster studies have become focused on global and general human predicaments, in keeping with other late 20th Century problem areas. Awareness of environmental hazards peaked in the late 20th Century, culminating in the United Nations Conference on Environment and Development in Rio de Janeiro (the "Rio Summit") in 1992. Furthermore, in recognition of the disastrous impact of natural hazards on vulnerable communities, the United Nations General Assembly adopted Resolution 44/236 in December 1989, proclaiming the 1990s as the International Decade of Natural Disaster Reduction (IDNDR, 2000). Its objectives were to reduce loss of life, property damage and social and economic disruption caused by natural disasters, particularly amongst poor, vulnerable populations in the developing parts of the world (IDNDR, 2000). These principles were affirmed at the World Conference on Natural Disaster reduction at Yokohama in 1994, where the Yokohama Strategy and Plan of Action for a Safer World was adopted as an international blueprint for disaster reduction (ISDR, 2004). Disaster prevention, mitigation, preparedness and relief, linked to the concept of sustainable development and planning, were emphasised as appropriate measures to counter the effects of natural hazards (IDNDR, 2000). As successor to the IDNDR, the UN General Assembly founded the International Strategy for Disaster Reduction (ISDR). The core focus of ISDR remains the building of disaster resilient communities by increasing global awareness of the inextricable link between disaster reduction and sustainable development (ISDR, 2004). In the most recent development, the Hyogo Framework for Action: 2005-2015: Building the Resilience of Nations and Communities to Disasters was adopted as a guiding framework for the next decade at the World Conference on Disaster Reduction in Kobe, Hyogo in January 2005 (ISDR, 2005). Governments from 168 countries adopted a ten-year plan to reduce losses from natural disasters. Underscoring the intrinsic relationship between disaster reduction, sustainable development and poverty eradication, the framework's overriding objective is the reduction of vulnerability and risk by building national and community resilience. Significantly, these same principles and priorities form the core of the recently promulgated Disaster Management Act (2002) and National Disaster Management Framework (2005) in South Africa.

The multidisciplinary and applied nature of hazard studies widened to the point where earlier distinctions between natural and man-made became increasingly blurred (Smith, 1992; Cutter, 1993). Researchers today emphasise the importance of the social production of human vulnerability in hazard studies. Disasters are seen as the result of the interaction and complex combination of vulnerability and hazard (Blaikie *et al.,* 1994; Hewitt, 1997).

Although multidisciplinary and interdisciplinary, authors argue that natural hazards, disasters and risk are essentially geographical in nature (Cutter, 1993; Hewitt, 1997). While sociologists, psychologists, economists, geologists, epidemiologists, *etc.* have made valuable contributions to the understanding of hazards from their particular perspectives, geography is seen to provide critical questions and answers in terms of scale, location, setting, distribution and pattern of hazards and disasters and the myriad interrelationships amongst these (Cutter, 1993; Hewitt, 1997). Geographers explore the risks arising from or within the realities of particular places and their problems (Hewitt, 1997). Geographers, too, are particularly well placed to approach hazards from an integrated human-environment analytical framework, which focuses on the physical properties of natural resources and how and why society uses them (Vogel, 1992). Cutter (1993) argues for an eclectic approach amongst hazard researchers (which would include geographers by definition), employing a wide range of methods: spatial, contextual, historical, narrative and quantitative. Such an approach encourages comparisons and provides a more comprehensive understanding of hazards (Cutter, 1993).

Several authors have attempted to delineate broad approaches or schools of thought in disaster studies, based on research and study perspectives that have developed over time. Smith (1996) distinguishes between two broad approaches, *viz.* behaviouralist and structuralist. The behaviouralist approach emphasises the environmental and technocratic aspects of hazards and disasters (Smith, 1996). He further asserts that this approach has been the dominant view from governments and disaster management agencies, based on a

Western understanding of hazard and disaster, and relies too heavily on the role of technology in disaster mitigation (Smith, 1996). The structuralist approach, on the other hand, focuses on the underlying political and economic determinants of disasters. It is a radical perspective which refutes the notion that science and technology can on their own solve problems, rather solutions are based on the redistribution of wealth and power, which will allow more equitable access to resources. This approach is particularly relevant to hazard and disaster experience in Third World countries (Smith, 1996). Both approaches have their critics, but Smith (1996) calls for a compromise between these two paradigms, allowing for a balanced approach which emphasises the importance of applied research. Similarly, Blaikie *et al.* (1994) and Wisner *et al.* (2004) distinguish broadly between two divergent views, *viz.* naturalist (or physicalist) and political economy/ecology approaches. The first lays all blame on nature's violent forces while the second focuses solely on the social and political production of disasters. Blaikie *et al.* (1994) adopt an approach which, while recognising that natural forces play a role in disasters, places heavy emphasis on how social systems operate in making people vulnerable to disasters. "Underlying factors" and "root causes" are at the core of the two models they propose to explain the concept of vulnerability, *viz.* the Pressure and Release Model (PAR) and the Access Model.

Alexander (1993 and 1997) suggests that the field of hazards and disasters has suffered from over-specialisation and hence fragmentation. He identifies six schools of thought and expertise on hazards and disasters: geographical approach, anthropological approach, sociological approach, development studies approach, disaster medicine and epidemiology and the technical approach. He adds further that all these schools of thought deal with essentially the same phenomenon, which is counter-productive to developing an holistic, embracing theory and the formation of a distinct discipline. Most hazard theory, too, has been developed for the developed word and may not be as relevant to other less developed parts of the world (Alexander, 1993). In addition, "academic tribalism" and consequent over-specialisation has retarded the development of rigorous inter-disciplinary theory (Alexander, 1997; Fara, 2000).

Tierney *et al.* (2001) cite four theoretical approaches: early functionalist/systems, natural hazards, social scientific and more recent approaches aligned to social constructionism and political-economy perspectives. The authors argue that discipline-related differences have impeded the integration of hazard and disaster theory, yet do provide some evidence of an emerging closer collaboration between hazard research and disaster research, which traditionally have been seen as almost discrete specialisations (Tierney *et al.,* 2001).

Tobin and Montz (1997) trace the development of theoretical approaches over a period of time, from the very early environmental determinism perspective of Huntington and Semple, through the traditional physical science perspectives of the 1960s, to the more recent approaches which underscore the critical importance of social processes in defining human vulnerability. The authors argue for an interdisciplinary, integrative approach to the study of hazards and disasters, also citing the problem of compartmentalisation into numerous sub-specialisations. In particular, the authors suggest that there is a scarcity of rigorous analytical models to investigate multiple hazards in one location. They argue for relevant, applied research, based on sound theory "… hazard scientists have a moral obligation to pursue *applied* research, seeking out real solutions to societies' problems" (Tobin and Montz, 1997; 322). While the value of applied research is readily discernible, Holloway (2003) points out that in southern Africa it is in fact the applied orientation of disaster studies which has discouraged national funding of local research initiatives in the disaster risk field, as it is not perceived as a field worthy of scientific study.

An alternative view is provided by Cutter (1993), who asserts that hazards research had its early origin in two social science disciplines, *viz.* sociology and geography, referring to the seminal works of Quarantelli and of White in the 1960s. Various schools of thought have evolved from these origins, in particular a "technological hazard" perspective. More recent approaches embody social theory and the social "amplification" of risk and even feminist perspectives on hazards and risks. Cutter (1993) draws a distinction too between a long-standing problem of academic hazards researchers and risk professionals who use divergent approaches in studying hazards. The research community uses an amalgam of qualitative and quantitative techniques, while the risk professionals prefer exact quantitative (mathematical) risk assessment techniques (Cutter, 1993). Highlighting the critical importance of vulnerability in any hazard research, Cutter (1996) proposes a "hazards of place model of vulnerability " in which geographic locality is seen as the critical factor in defining risk and vulnerability. The model allows for both single and multi-hazard approaches, different political and socio-economic contexts and various methodological approaches. Geographic scale and context and pattern are key elements in Cutter's (1996) model. Similarly, both Alexander (1993, 1997) and Tobin and Montz (1997) emphasise the importance of locality and contextual factors in examining hazards and vulnerability.

More recently, the United Nations University: Institute for Environment and Human Security proposed two models for examining vulnerability and risk: a so-called 'onion model' and a 'BBC model' after Bogardi, Birkmann and Cardona (Brauch, 2005). A critical aspect of both models is the realisation that vulnerability can be reduced significantly by the coping capacity of a system (Brauch, 2005). Importantly, Blaikie *et al.'s* (1994) conceptualisation of risk as the product of hazard and vulnerability is also visible in both the 'onion' and 'BBC' model.

Another critical issue in the field of disaster studies is the artificial bifurcation of the hazards community into academic researchers and risk professionals (Cutter, 1993; Fara, 2000). More recently, however, a synthesis and greater collaboration between interdisciplinary academic and professional interests has been placed on the international agenda (ISDR, 2004).

2.4 Key definitions

Not unexpectedly, problems of definition are endemic to the hazard and disaster field of inquiry (Cutter, 1996; Alexander, 1997; ISDR, 2004). Key terms such as hazard, risk, disaster and vulnerability have been defined very differently by various authors over the years, depending on their own epistemological orientations and subsequent methodological practices (Cutter, 1996). There have, however, been attempts towards standardizing key definitions within the hazard field, as encapsulated by the ISDR (2004), pp.16-17:

Hazard: "A potentially damaging physical event, phenomenon or human activity that may cause the loss of life, or injury, property damage, social and economic disruption or environmental degradation."

Vulnerability: "The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards."

Risk: "The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally, risk is expressed by the notation *Risk = Hazards x Vulnerability*." (author's emphasis)

Disaster: "A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources."

The term "disaster" carries with it connotations of large-scale, infrequent events (Holloway, 1999). Within an African context, it is perhaps more important to keep track of the 'small-scale' disasters at household or community level, where "every day is accompanied by significant natural and manmade dangers" (Holloway, 1999; 207). Lewis (1999; 4) makes this same point even more strongly, "Categorization of disasters by magnitude reflects a remote and privileged comparative view which tends to exclude disasters of a lesser degree, even though locally these may represent catastrophic national and local impacts". Accordingly, this study will investigate the full range of severe storms, ranging from low to high frequency and from low to high magnitude events.

2.5 Summary

The field of disaster studies or disaster risk science has evolved over time to become a specialisation in its own right. Essentially, it is seen as an integrating, embracing science which seeks to combine conceptual approaches and methods from a number of disciplines. This chapter has emphasised the importance of "geography" in the study of natural hazards, disasters and risk, where locality and context play a critical role in determining local and regional variations.

CHAPTER THREE: SEVERE CONVECTIVE STORM HAZARDS

> *The intensity of a hazard cannot be expressed independently of human factors*.
>
> Tobin and Montz, 1997; 5

3.1 Introduction

The purpose of this chapter is to provide a comprehensive critical analysis of the theoretical and contextual aspects of severe convective storm hazards and to link this to key research undertaken in the field.

3.2 Classification schemes

Within the broad spectrum of natural hazards, authors have delineated a discrete category of climatic/meteorological hazards, for example Burton and Kates (1964), Bryant (1991) and Jones (1991). Others, such as Smith (1992), prefer to use the term “atmospheric” hazards. Included in these classifications are fog, snow, frost, hail, lightning, tornadoes, windstorms, temperature extremes, *etc.*, where the emphasis rests heavily on the geophysical processes as a causal agent (Smith, 1996). Jones (1991), however, further distinguishes between climatic/meteorological hazards of geophysical origin and those of quasi-natural or human-accentuated origin, such as smog and global warming. Importantly, Smith (1997) and Tobin and Montz (1997) point out that in many cases climatic hazards are not single element hazards, such as rain or hail, but are more often compound element events, such as thunderstorms and tornadoes, where multiple elements can combine to increase the threat. This is shown in Figure 3.

The researcher asserts that this classification scheme is particularly pertinent to this study, where many of the severe storms occurring in the Eastern Cape are compound; storms produce various combinations of hail, wind, tornado, lightning and flash flooding, thereby increasing the threat to and impact on people.

Figure 3 Classification of climatic hazards

SINGLE-ELEMENT EXTREMES (common hazards)	COMPOUND-ELEMENT EVENTS (primary hazards)
Temperature Precipitation Snowfall High winds	Cyclones : wind + rain Blizzards : wind + snow Thunderstorms : rain + lightning Tornadoes : vortex + extreme winds Glaze storms : rain + frost
SINGLE-ELEMENT EXTREMES (less common hazards)	**SECONDARY HAZARDS (derived from climate elements)**
Lightning Hail Fog	Floods Droughts Wildfires Avalanches Landslides Epidemics

Source: Adapted from Smith (1997; 305)

3.3 Severe convective storms: a problem of definition

It is important to differentiate severe convective storms from other kinds of severe storms. Authors use the term loosely and in many cases the terms "storm" or "severe storm" are used generically to include severe convective storms and other types of severe weather systems such as hurricanes, tropical depressions and extra-tropical cyclones, for example Bryant (1991), Wernly (1994) and Smith (1996).

Severe convective storms are almost always a summer season phenomenon and are associated with a range of hazards: tornadoes, damaging winds, hail, lightning and flash flooding (Alexander, 1993; Smith, 1996). Authors refer also to "severe summer storms" (Smith, 1996) or " severe thunderstorms" (Wernly, 1994). For the purposes of this study the terms "severe convective storm" and "severe thunderstorm" are understood to represent the same phenomenon and are used interchangeably. In addition, for the sake of brevity, the contracted terms "severe storm" and "storm" are used throughout this study to signify a "severe convective storm".

According to the National Severe Storms Laboratory (NSSL) and the NWS (National Weather Service) in the United States, a severe thunderstorm is classified according to the following criteria:

Severe storm includes one or more of:

- Hail ≥ 19mm diameter, wind gusts ≥ 50 knots (92km/h), tornado

Significant severe includes one or more of:

- Hail ≥ 50mm diameter, wind gusts ≥ 65 knots (120km/h), tornado ≥ F2

(Concannon *et al.,* 2000; Crisp *et al.*, 2001; Brooks, 2005;)

It is suggested that such precise classifications are only possible where highly advanced recording, observation and spotter networks allow for exact and reliable measuring of meteorological parameters, such as wind speed and hail size. It must be pointed out that this is not the case in South Africa and that in many areas, such as the Eastern Cape, the converse holds true (Pyle *et al.*, 1999; Roux, 2003). The particular South African situation militates against adhering to rigidly defined objective criteria, such as those used in the United States. Difficulties and problems associated with accurate and reliable reporting and recording are dealt with in the following sections.

Accordingly, for the purposes of this study, and within the local South African context, a severe convective storm is defined as:

An intense, localised, short-duration thunderstorm accompanied by damaging winds (including tornadoes), hail, lightning and flash flooding.

Whilst the above definition may be criticised as lacking quantifiable criteria such as hail size and wind speed, the researcher believes that the definition is sufficiently precise for this study, yet allows for more flexibility in terms of including a reasonably broad range of intensity and impact of reported storms, in contrast to the very rigid definition used by the NSSL and the NWS.

3.4 Thunderstorm types and models of development

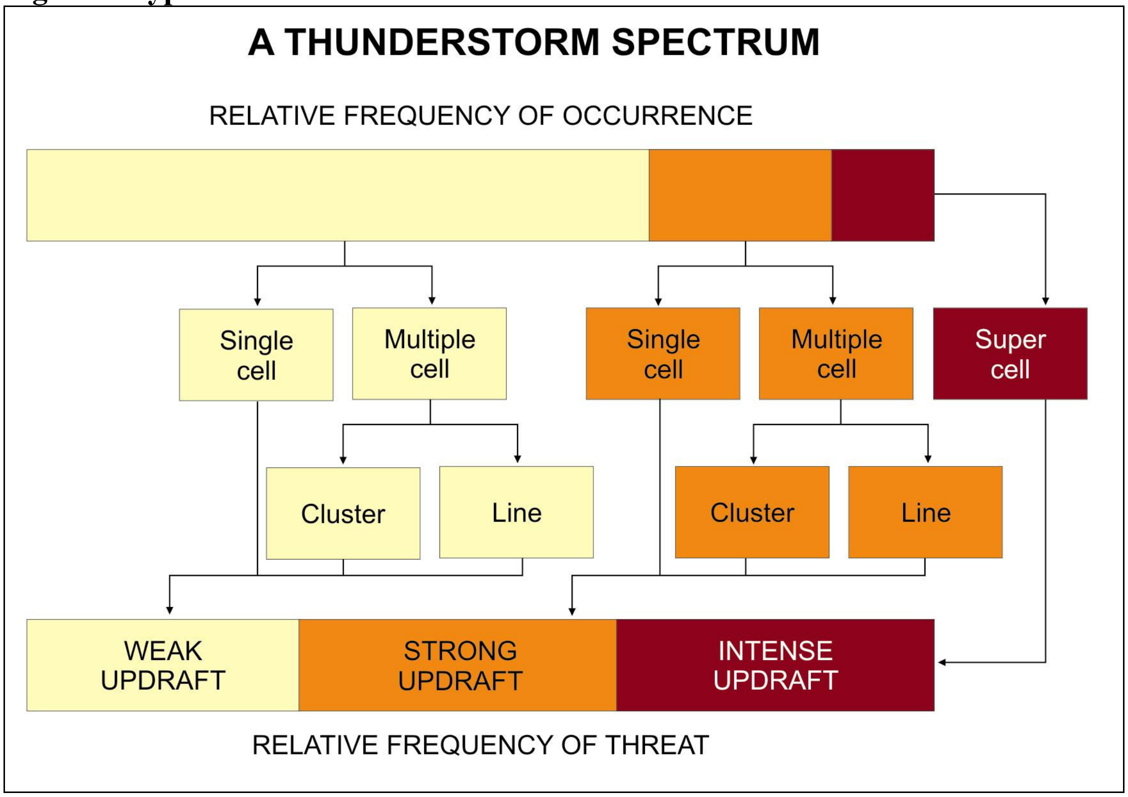
The aim of this section is to provide a synopsis of the major types and characteristics of thunderstorms and to review past and current thinking on their formation and development, with particular reference to the South African and Eastern Cape contexts.

Classifying thunderstorms according to the stages of development or life cycle, *viz.* cumulus, mature, dissipating is perhaps the most frequently encountered method in the literature, for example Moran and Morgan (1997) and Tyson and Preston-Whyte (2000). Whilst this classification is useful, it is too simplistic as it does not explain the various types of thunderstorms which develop through these stages.

Thunderstorms have traditionally been divided into three main types, based on the processes at work and their associated physical/climatological features: single-cell, multi-cell and supercell (Tyson and Preston-Whyte, 2000). These may occur as isolated, scattered, line or cluster storms. A variety of atmospheric conditions, such as wind shear, strength of upper winds, atmospheric instability, *etc.* will determine what types of thunderstorms and in what formation they will develop over a given area. The main thunderstorm types are shown in Figure 4.

Single-cell storms tend to produce isolated storms of only weak to moderate intensity. Multi-cell storms consist of a cluster of single cells of longer horizontal extent, have longer duration, are more intense and can produce severe weather. Many of the so-called 'Highveld' thunderstorms in South Africa are of this type. Pioneering work on the development of Highveld line thunderstorms, which are predominantly multi-cellular, was completed by Taljaard (1958) and is still regarded as the best model for understanding such storms in South Africa. Worth noting is the formation of a particular large-scale multiple cell storm type known as a Mesoscale Convective Complex (MCC) or a Mesoscale Convective System (MCS). These may be described as a large grouping of thunderstorms which may cover several hundred kilometres and may last for 6-24 hours. MCCs and MCSs are arranged in a spherical shape and are large enough to cover an entire state in the United States of America (USA) (Moran and Morgan, 1997). In

Figure 4 Types of thunderstorms



Source: Adapted from the University of Illinois, no date

many cases MCCs and MCSs are responsible for producing very severe weather in the form of tornadoes, high winds and hail. MCCs are known to occur in the Eastern Cape, but very infrequently; it is postulated that the very destructive Mount Ayliff tornado in 1999 was associated with an MCC (van Niekerk, pers. comm., 2006).

Supercell storms are the least frequent, yet most intense and potentially damaging of all types. Geer (1996; 221) defines a supercell as:

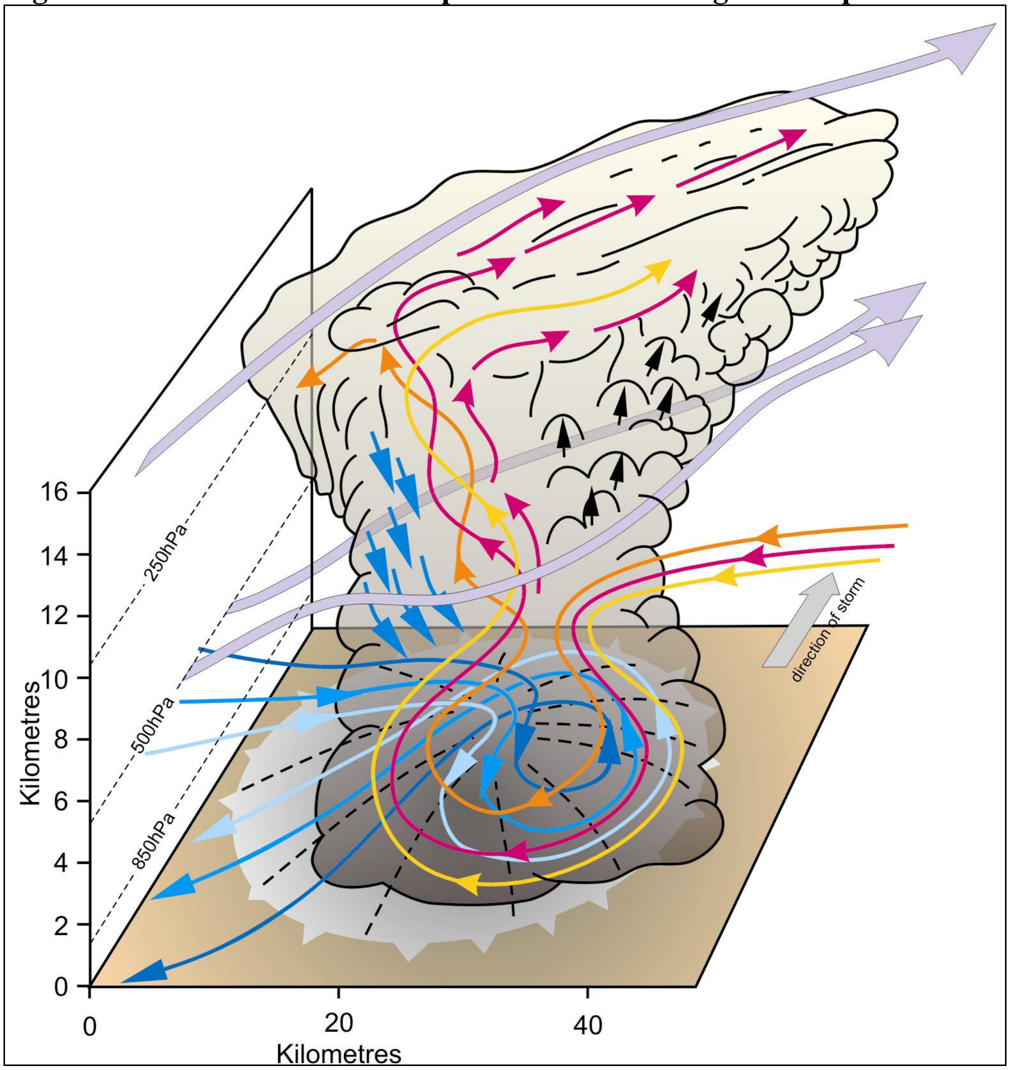
"Persistent, single, intense updraft (usually rotating) and downdraft co-existing in a thunderstorm in a quasi-steady state rather than in the more usual state of an assemblage of convective cells, each of which has a relatively short life; often produces severe weather including hail and tornadoes".

These types of storms are much larger, of longer duration (up to 6 hours) and produce more severe weather than other types of thunderstorms, in the form of giant hail, damaging surface winds and less frequently long-lived major tornadoes (Geer, 1996). The classic model of the development of a supercell thunderstorm was first developed by Browning and Ludlam (1962) and subsequently revised by Browning and Foote (1976). Tyson and Preston-Whyte (2000) synthesised the ideas of the aforementioned theorists and devised a model of a southern African supercell thunderstorm, shown in Figure 5. Although the authors specify that the model represents a Highveld supercell storm, the researcher asserts that supercell storms in the Eastern Cape would develop similarly, given that the prerequisite ingredients in supercell storm formation discussed below have been found to occur in the Eastern Cape under certain synoptic and thermo-dynamic situations (de Coning and Adam, 2000).

Important ingredients in the formation of a supercell thunderstorm are strong potential and conditional instability, pronounced wind shear in the middle layers and warm moist low-level air overlain by middle-level cool, dry air. These factors combine to form a rotating updraft called a mesocyclone (Moran and Morgan, 1997; Tyson and Preston-Whyte, 2000).

A further important distinction is made by climatologists between tornadic and non-tornadic storms. De Coning and Adam (2000) and Brooks (2004, 2005) point out this difference, which is based primarily on the measurement of atmospheric instability parameters, such as Convective Available Potential Energy (CAPE), Lifted Index (LI), Showalter Index (SI) and Sweat Index. In addition, indices have been developed to measure the strength of wind shear, an important factor in producing mesocyclones, e.g. vertical wind shear, Bulk Richardson Number (BRN) and Storm Relative Helicity (SRH). The intensity of radar core reflectivities and Tornadic Vortex Signatures in the form of so-called “hook” and “bow” echoes are important indicators of storm intensity and are used to discriminate whether a storm is tornadic or non-tornadic (Visser, 2001; Przybylinski, 2004).

Figure 5 A three-dimensional representation of a Highveld supercell storm



Adapted from Tyson and Preston-Whyte, 2000; 111

Very recently, even more advanced techniques have been developed locally and internationally to provide more accurate forecasting of storms. A satellite-derived Global Instability Index is currently in operational use by the South African Weather Service (SAWS) to complement the use of more traditional weather prediction models (Koenig and de Coning, 2006). In addition, the use of Meteosat 8 or Meteosat Second Generation (MSG) data now allows forecasters an enhanced ability to identify and track the evolution of thunderstorm development from individual cells to synoptic scale (Rae and Clark, 2005). The values of the various indices and the MSG data provide an indication of whether a storm is severe or non-severe and whether tornadic or non-tornadic (d'Abreton, 1991; de Coning and Adam, 2000; Roux, 2003; Brooks *et al.*, 2003). It is generally accepted that such distinctions are extremely valuable for forecasting severe storms, especially for use in operational "nowcasting", which are very short-term forecasts varying from minutes to a few hours (Geer, 1996; Visser, 2001; Roux, 2003). Importantly, spatially accurate and timeous nowcasts can be used in effective early warning of rapid-onset storms, particularly at a local level (Rae and Clark, 2005). Tracking the development and movement of severe storm cells over a short period of time and over a small area allows disaster management officials and local communities to be warned in advance of any impending severe weather in order to take the necessary precautions (Poolman, 2006). In the Eastern Cape, severe storm nowcasts are relayed by cell phone SMS from the SAWS Port Elizabeth Regional Office to provide precise information on the intensity, location, direction and speed of movement of severe convective cells that have been identified by radar and satellite. This critical information is disseminated to local disaster management officials, who have the responsibility of warning at-risk communities which may be in the storm path. The SAWS early warning system is discussed in more detail in Chapter 4 (section 4.3.2).

3.5 Thunderstorm hazards

Whilst the previous section provided an overview of the types of thunderstorms and their development, this section provides a more detailed discussion and analysis of the associated thunderstorm hazards.

All thunderstorms, severe and non-severe, tornadic and non-tornadic, may produce damaging winds, hail, lightning and flash flooding, either singly or in combination, of varying duration, extent and intensity. This study is concerned with the severe end of the spectrum of thunderstorms, hence emphasis will be placed on the potentially damaging impact of severe weather associated with thunderstorm hazards. To provide the context, the researcher will also present accepted theoretical explanations of the formation of these hazards, but a detailed, critical analysis of all the theories of formation will not be presented, as this falls beyond the aims and scope of this study.

3.5.1 Damaging winds

Damaging winds associated with severe thunderstorms include tornadoes, downbursts (macrobursts or microbursts), straight-line winds, gust fronts and derechoes.

3.5.1.1 Tornadoes

Tornadoes are generally accepted to produce the most intense and damaging winds. Geer (1996; 233) defines a tornado as:

"A small mass of air (whirlwind) that spins rapidly about an almost vertical axis and forms a funnel cloud that contacts the ground; appears as a pendant from a cumulonimbus cloud and is potentially the most destructive of all weather systems. Tornadoes have diameters ranging from ten meters to over several hundred meters".

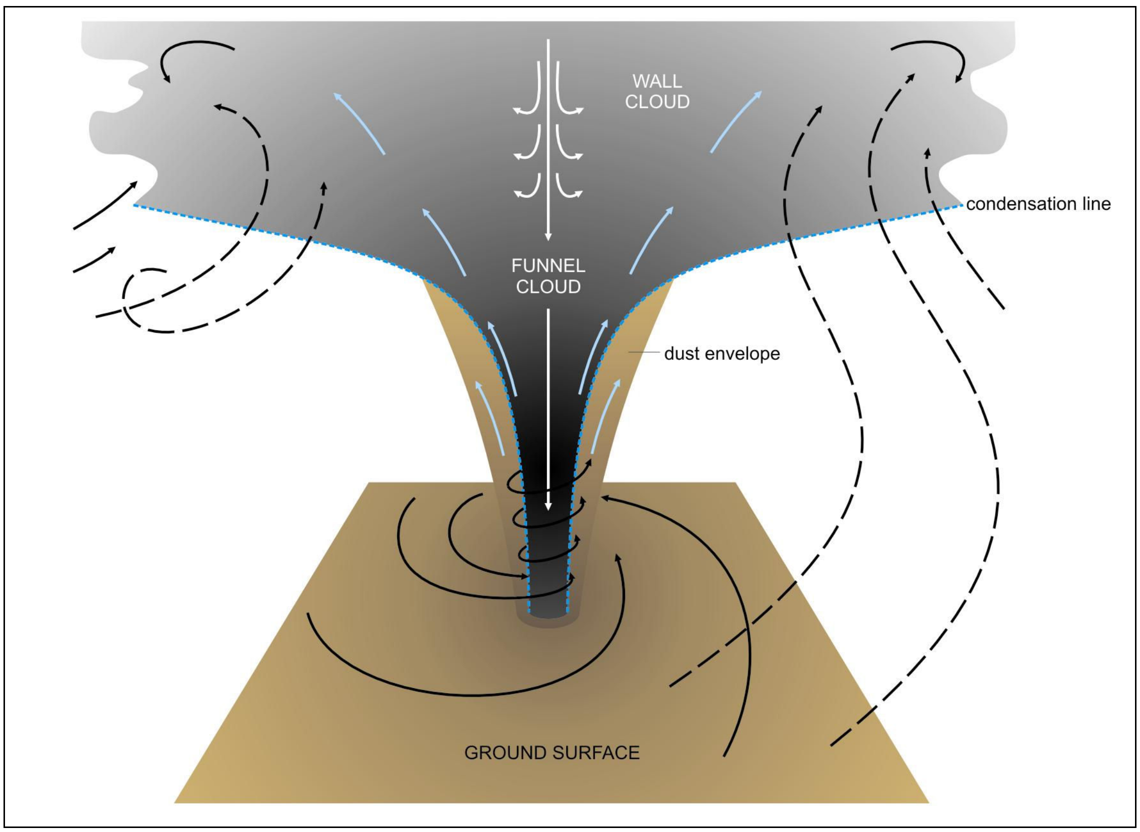
Tornadic formation (termed tornadogenesis) within a severe thunderstorm is still the subject of intense debate amongst meteorologists, but there seems to be general agreement that certain key atmospheric ingredients appear to enhance for their formation:

- Extreme atmospheric instability (this is measured by using indices such as CAPE, LI, SI, *etc.*)
- Strong wind shear (this is measured by using indices such as BRN and SRH, *etc.*)
- A deep layer of mid-atmospheric dry air above a moist, warm tongue-shaped surface layer
- Steep moisture and temperature gradients, including the presence of a marked surface "dryline" separating dry, cool air from warm, moist air in a west-east orientation
- High surface temperatures, usually associated with summer convectional heating
- Strong low-level convergence and upper-air divergence

These key ingredients and atmospheric conditions have been synthesised from the following authors and are based primarily on work conducted on empirical case studies, using mainly global re-analysis data: d'Abreton (1991), Goliger *et al.* (1997), Brooks *et al.* (2003), Roux (2003) and Brooks (2004).

The exact processes responsible for the formation of a funnel and subsequent tornado are not known yet. Funnels are theorised to develop in the rotating mesocyclone section of the supercell storm as a result of strong vorticity, temperature gradients, convergence, and very strong updrafts and downdrafts, which cause deflection and subsequent violently rotating winds. The funnel descends from the base of the cloud, usually signified by a low rotating wall cloud, and once it touches the ground it becomes a tornado (Alexander, 1993; Goliger *et al.*, 1997; National Oceanic & Atmospheric Administration [NOAA], no date). Further research into the exact "trigger" mechanism, in relation to all the physical and atmospheric processes involved, still needs to be done. Figure 6 shows the structure of a funnel cloud and tornado.

Figure 6 Structure of a tornado



Adapted from Alexander, 1993; 172

Of great significance is the potentially lethal damage which can be inflicted by the exceptionally strong winds that are generated by tornadoes. In the most powerful tornadoes, the rotational speed of winds have been estimated to reach 400-500 km/h, especially when embedded multiple suction vortices form in the funnel (Alexander, 1993; Moran, no date). An fuller indication of their intensity and magnitude is provided in the following section.

Tornadoes and associated severe weather hazards occur in many areas of the world where favourable atmospheric environments exist. Brooks (2004) cites certain high frequency areas where storms are likely to be severe, including the Great Plains of the USA, south-eastern Brazil, areas near the Himalayas, and significantly, the extreme south-eastern Africa (which would most likely concentrate on KwaZulu-Natal and the eastern areas of the Eastern Cape).

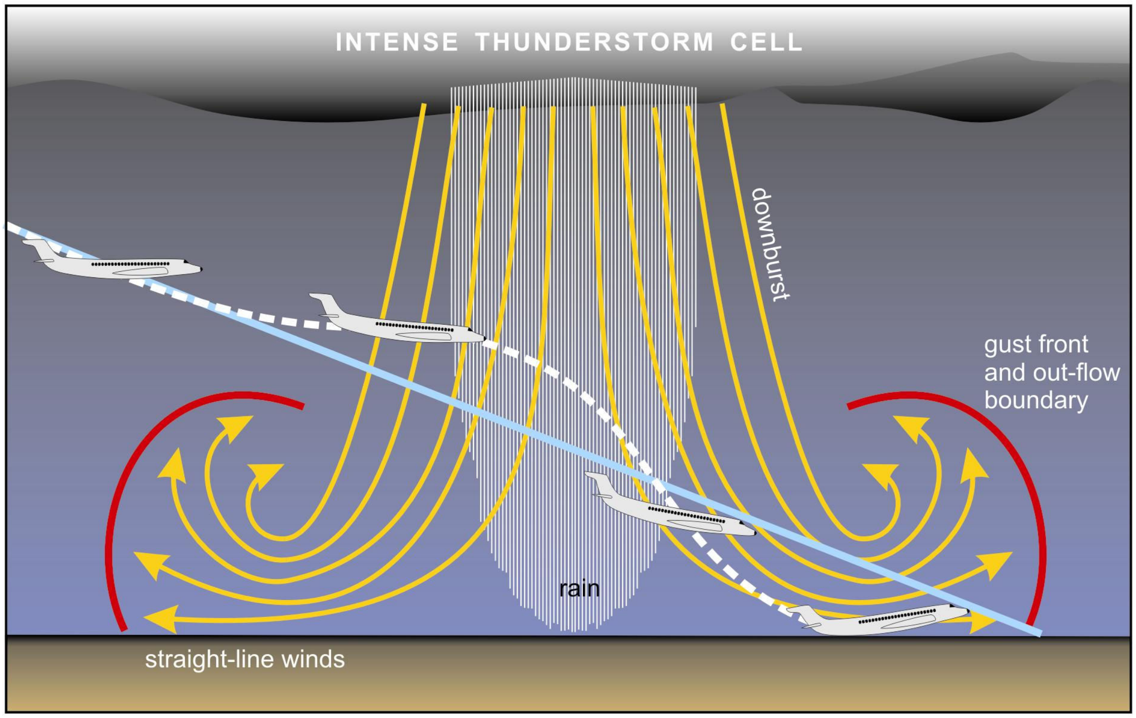
3.5.1.2 Downbursts, gust fronts, straight-line winds and derechoes

A downburst may be defined as:

"An exceptionally energetic downdraft that exits the base of a thunderstorm and spreads out at the earth's surface as strong and gusty horizontal winds that may cause property damage" (Geer, 1996; 70-71).

Downbursts may occur as either microbursts and macrobursts. The essential difference is one of scale and duration: macrobursts affect a larger area and are of longer duration. Winds may reach 280km/h in exceptionally powerful events (Geer, 1996). The pattern of damage resembles a star-burst, which is distinct from the convergent damage patterns evident in tornadoes (Moran, no date). Figure 7 shows the potentially hazardous effects of downbursts.

Figure 7 Formation of downbursts, gust fronts and straight-line winds



Adapted from NOAA, no date

Gust fronts, straight-line winds and derechoes develop along the leading edge or outflow boundary of an advancing thunderstorm, shown in Figure 7. Straight-line winds, usually blowing from one direction, as distinct from rotational winds in tornadoes, develop in association with gust fronts and may cause considerable damage, with winds of up to 160km/h. The term "derecho" is used to describe larger scale straight-line winds advancing very quickly ahead of a well organised, long-lasting squall line or an MCC. (Geer, 1996; Moran, no date).

Given that the majority of severe thunderstorms in the Eastern Cape are most probably non-tornadic, the researcher asserts that downbursts and straight-line winds, as opposed to tornadic winds, account for much damage to property and livelihoods in the province. This will be examined further in the following sections.

3.5.2 Hail

Geer (1996; 107)) describes hail as:

"a type of frozen precipitation in the form of balls or irregular lumps of ice, usually consisting of concentric layers of ice".

Formation of hail occurs as a result of very strong updrafts in convective thunderstorms of considerable vertical development. These updrafts carry hail into the uppermost ice regions of the cloud, which then fall into the supercooled layer below, which is still liquid at a temperature of less than 0°C. Very often hailstones are then lifted again by very strong updrafts back into the freezing upper part of the cloud again, where more clear ice and rime coalesce into consecutive layers on the hailstone. This vertical re-circulation may continue for some time but once the mass and weight of the hail is too great to be supported by air currents within the storm cell it falls to the ground (Geer, 1996; Tyson and Preston-Whyte, 2000; Alexander, 2003).

Large hail can inflict injury and even death to humans and livestock, but the main damage is to property and crops (Alexander, 1993; Smith, 1996). Most areas of the world experience hailstorms of varying intensity. Significantly, South Africa is prone to severe hailstorms and loss to property and livelihoods reaches millions of Rands annually, as has been documented in CAELUM (1991). Significantly, Admirat *et al.* (1985) report that South Africa has a higher frequency of hail-days per year, compared with Switzerland and Canada. This thesis shows that the Eastern Cape, too, experiences a number of severe hailstorms annually with great cost to property and livelihoods. This appears to be in contradiction with hail frequency maps of South Africa produced by Schulze (1997), which exclude much of the Eastern Cape from the high frequency zones.

3.5.3 Lightning

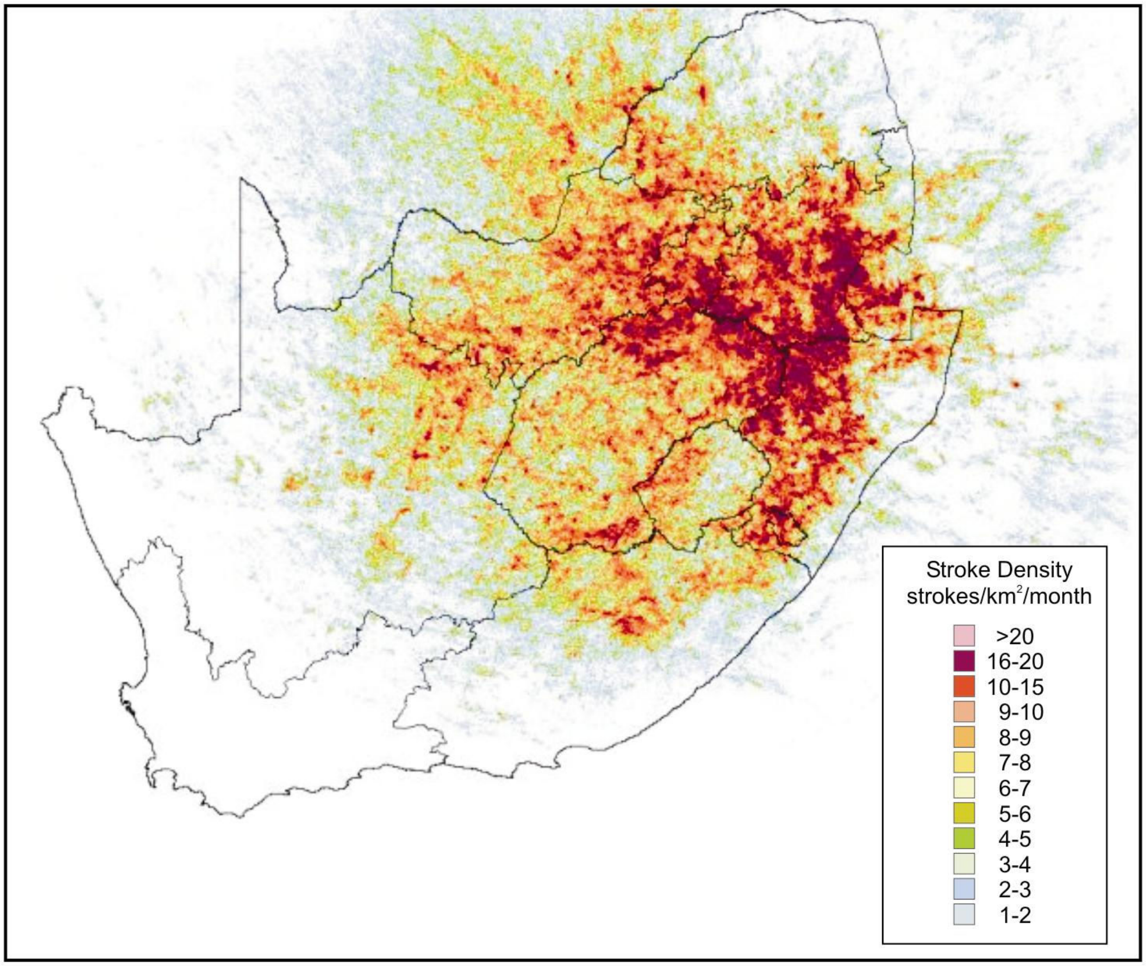
Geer (1996; 136) defines lightning as

"generally, any and all of the various forms of visible electrical discharge produced by thunderstorms".

Lightning is the defining hazard of all thunderstorms and is caused by the differential between the positively charged upper section of a cloud and the negatively charged lower section. The electrical potential gradient increases until a critical limit is exceeded and a sudden and violent discharge takes place. In cases where lightning strikes the earth, a discharge occurs between the negatively charged lower section of the cloud and the normally positively charged surface of earth (Alexander, 1993; Tyson and Preston-Whyte, 2000). Lightning can be cloud-to-cloud, cloud-to-air or cloud-to-ground (Tyson and Preston-Whyte, 2000).

Many authors emphasise the high cost of lightning in terms of injury and death (Alexander, 1993; Kithil, 1995; National Lightning Safety Institute, no date). Quantification of lightning hazard has not been high on the research agenda in most countries, but figures on lightning deaths in the United States suggest that lightning is the single biggest killer amongst all severe weather events, even surpassing deaths resulting from tornadoes and hurricanes (Kithil, 1995; National Lightning Safety Institute, no date). In South Africa, lightning density maps produced by the Council for Scientific and Industrial Research (CSIR) in 1994 (Schulze, 1997) appear to have significantly underestimated the frequency of lightning flashes. A new Lightning Detection Network (LDN) recently set up by the SAWS in South Africa has started generating data and preliminary results show that the number of lightning strikes far exceeds those previously recorded. Gill (2006) states that early results from the LDN suggest that lightning densities in South Africa compare favourably with Tampa in the USA, which has one of the highest densities globally. Of even greater significance is the fact that South Africa has six times more lightning deaths (measured in deaths per million people) than the

Figure 8 Lightning ground stroke density for December 2005 to March 2006



Adapted from South African Weather Service, 2006

global average (Gill, 2006). Figure 8 shows the average ground stroke density for the period December 2005 to March 2006. Of significance are the high densities in the northern and north-eastern parts of the Eastern Cape, running roughly in line with the escarpment. Deaths and injuries from lightning are greatly under-reported and under-estimated in the Eastern Cape (Sampson, pers. comm., 2006; Mpiti, pers. comm., 2006). It is strongly suggested that were more reliable lightning statistics available for the province, lightning would possibly account for many more deaths than those caused by other thunderstorm hazards.

3.5.4 Flash floods

Flash floods can be caused by very localised, almost stationary thunderstorms, where an exceptionally deep layer of unusually humid air is present, and where the amount of potential precipitable water in the clouds is very high (Geer, 1996; Moran, no date). Intense rainfall occurs over a relatively small area leading to a sudden influx of water into a drainage basin. This water in turn fills the streams and rivers in the basin and the water races downstream in a high peak discharge, with little or no advance warning. Factors affecting the speed of onset of a flash flood include the intensity and duration of the rain, the topography, soil conditions and ground cover (NOAA, no date). In arid regions where watercourses are often dry, sudden episodic flooding can lead to potentially high levels of damage and loss of life.

In remote rural areas the threat of flash flooding is high, where advance early warning systems are poorly developed or even absent. The researcher asserts that this is often the case in many rural areas of the Eastern Cape.

3.6 Measuring intensity and severity of severe storms

Authors have made efforts to classify severe storms according to spatial/temporal parameters such as frequency, areal extent, duration, rate of onset, predictability and intensity, for example Bryant (1991) and Alexander (1993). Of these, intensity appears to be most widely used.

3.6.1 Tornado intensity

The most commonly used measure of intensity for severe storms is the Fujita-Pearson (FPP) Scale, based on the work of Fujita (1971, 1973) and his later collaboration with Pearson in 1973, which in practice ranks tornadoes from F0 (min) to F5 (max). This is based essentially on the scale of damage impact of a tornado, path width and path length. Measurement of these three variables are done *in situ* after an event. Wind speeds are derived from these descriptors, shown in Table 1.

Table 1 Fujita / Pearson tornado scale (after Fujita, 1973)

Maximum wind speed (m/s)		Path length (km)		Path width (m)	
F0	20-30	P0	0.5-1.5	P0	5-15
F1	30-50	P1	1.5-5.0	P1	15-30
F2	50-70	P2	5.0-16	P2	30-160
F3	70-90	P3	16-50	P3	160-510
F4	90-115	P4	50-160	P4	510-820
F5	115-140	P5	160-500	P5	820-2800
Damage descriptors					
F0	Light damage: some damage to chimneys, branches of trees broken, shallow-rooted trees over, signboards damaged.				
F1	Moderate damage: roof surfaces peeled off, mobile houses pushed off foundations and overturned, moving cars pushed off the road.				
F2	Considerable damage: roofs torn off frame houses, mobile homes demolished, boxcars pushed over, large trees snapped or uprooted, light-object missiles generated.				
F3	Severe damage: roofs and some walls torn off, well-constructed houses overturned, most trees in forest uprooted, heavy cars lifted off the ground and thrown.				
F4	Devastating damage: well-constructed houses levelled, structures with weak foundations blown off some distance, cars thrown and large missiles generated.				
F5	Incredible damage: strong-framed houses lifted off foundations and carried considerable distance to disintegrate, automobile-sized missiles fly through the air in excess of 100 m, trees debarked, incredible phenomena will occur.				

Source: Goliger and de Coning, 1999; 3

There are, however, a number of limitations to the FPP scale and these are detailed below:

- The scale has never been scientifically tested and there is no definitive correlation between wind speed and damage.

- The scale can be used to rank downbursts (up to F3), (Dotzek, pers. comm., 2005), but other types of severe storms of remain unclassified.
- Impact severity will depend on the type and quality of building construction and materials used and the scale does not allow for sufficient damage indicators (Goliger *et al.*, 1997).
- Low F scale tornadoes are more likely to be missed and not reported, whereas highest F scales are also likely to be underestimated (Brooks and Doswell III, 2001).
- The scale is difficult to apply consistently and there are errors in the subjective assigning of an F scale – damage surveyors often disagree by at least 1 F scale for an event (*ibid*, 2001).
- Damage surveys need to be completed within a maximum of two days following an event to assess the storm damage accurately (de Coning and Adam, 2000). This is not always possible, especially with respect to the South African situation.

In response to the shortcomings and limitations of the Fujita-Pearson scale, the United States has very recently devised an Enhanced F Scale (EF Scale) for operational use in 2007. The revised scale has included 28 comprehensive damage indicators for each building type, building structure and trees. In addition, each damage indicator has 10 degrees of damage ranging from 'no damage' to 'total destruction' (Tew, 2006). Fundamental improvements on the FPP scale are less subjectivity, more accurate wind speed estimations and a better correlation between wind speed and damage (Tew, 2006). The new scale will continue to rate tornadoes from 1 to 5 but with reduced maximum wind speeds in the higher categories, in particular. Importantly, tornadoes in the historical database in the United States will not be re-classified (NOAA, 2006).

3.6.2 Hail intensity

Hail size is commonly used as another parameter to measure the intensity of severe storms. In countries such as the United States, where reliable measurement of hail size is obtained through hailpad data, a more accurate assessment of hail frequencies and hail severity can be obtained. In other parts of the world, where hailpad data are not readily available, the most commonly used hail severity scales are descriptive in nature, based on the reported hail size/diameter of hailstones. However, Visser (2006) adds that hail intensity fields can be derived from radar images in South Africa, based on hail frequencies in a particular area. This may be helpful in operational forecasting of severe hailstorms on a small scale.

In South Africa the CSIR/EMATEK research project on hail (1984-1995) classified hail according to 7 categories based on hailstone diameter from 3mm (rice) to >50mm (larger than hen's egg) (Rae, 2005). In the UK, the Tornado and Storm Research Organisation (TORRO) ranks hailstorms according to a hail severity scale (H scale) from H0 to H10, also based on hailstone diameter and descriptors (Webb *et al.*, 2005). In Australia, the Bureau of Meteorology uses similar sizes and descriptors such as golf ball, cricket ball, tennis ball, in addition to conventional hailpad data (Schuster *et al.*, 2005).

There are difficulties in terms of the possibility of reporting error due to the subjective assignment of a hail size category, although there is less room for large error compared with the tornado F scale.

3.6.3 Other intensity and severity indices

In the previous section, it has been pointed out that instability parameters derived from model fields, such as CAPE, Lifted Index, *etc.*, have been assigned threshold values to discriminate between severe and non-severe thunderstorms and between tornadic and non-tornadic thunderstorms. These parameters can assist operational forecasters to identify tornadic signatures in advance (de Coning and Adam, 2000) and are applied internationally. Vitart (2006) makes the point that although computer modelling and numerical simulations of severe storms may be helpful, substantial model errors may occur when dealing with highly complex atmospheric systems such as severe storms. Accordingly, Vitart (2006) advises that very fine resolution models are a prerequisite for nowcasting tornadoes and severe storms.

Weather radar is another technological tool used to track storms and to identify storm severity. Radar core reflectivities of 60dBZ and higher indicate very intense storm cells and the possibility of a severe storm. The Storm-Structure-Severity method devised by Visser (2001) in South Africa classifies storm cell severity according to 3 categories: Weak (30-44 dBZ), Moderate (45-50 dBZ) and Severe (>55 dBZ). Obviously, the use of such methods are only possible where effective weather radar networks have been established. The recently established radar station at Highbury near Umtata in the Eastern

Cape is intended to track rapid-onset storms in the high risk north-eastern areas of the province. Unfortunately, due to a problem of theft of critical components of the weather radar, it is very often not operational (Mpiti, pers. comm., 2006).

With the installation of the LDN in South Africa, the intensity of lightning will be able to be recorded for the first time in this country. An intensity scale based on the energy in each stroke will be measured in kiloAmps, where a value of approximately 50 kiloAmps signifies a very intense lightning stroke (Gill, 2006).

3.7 Trends in severe convective storm research

3.7.1 International scenario

Given that the USA experiences the highest frequency and severity of severe storms worldwide, the majority of research has dealt with the North American experience. Analysis of the physical nature and characteristics of severe storms in the USA remains a continued focus at various institutions involved in severe storm research, such as the National Severe Storms Laboratory (NSSL, a specialist arm of NOAA) at Norman, Oklahoma. The American Meteorological Society sponsors an annual Conference on Severe Local Storms in the USA. The 23rd Conference is due to be held in November of 2006 in St Louis, USA. Topics at the annual conferences cover traditional aspects on severe storm climatology, tornadogenesis, numerical modelling, hailstorms, *etc.*, yet an increasing amount of time is being devoted to issues related to the perception and response of the public to severe weather forecasts and warnings (Trapp *et al.*, 2001). Thus, there has been a growing trend towards examining the human and social aspects of severe storms, such as perception, risk, mitigation, early warnings, *etc.*, in line with recent trends in hazards research, which has broadened considerably to incorporate more of the social sciences (ISDR, 2004). Institutes such as the Natural Hazards Research Center at Boulder, Colorado, focus almost entirely on the behavioural and sociological aspects of severe storms and other natural hazards. In Britain, a privately supported research body, TORRO, has been engaged in research since 1974 on severe storms in the UK and Europe (Elsom *et al.*, 2001). The purpose of TORRO is to determine realistic spatial, temporal and intensity distributions of severe weather events in the UK and Europe (Elsom *et al.*, 2001). Severe thunderstorms are common phenomena in many

European countries, yet scientific studies are sparse compared with the USA (Snow, 2001). In the past few years, however, there has been a more concerted effort to raise the profile of severe storm research in Europe. Several research groupings have formed and in 2000 a Conference on European Tornadoes and Severe Storms was held in Toulouse, France. The purpose of the conference was to develop new insights into severe storm dynamics and forecasting worldwide and to foster further research co-ordination and collaboration (Snow, 2001). A follow-up European Conference on Severe Storms (ECSS) was held in Prague, Czech Republic in 2002 to further document and build awareness of severe convective storms in Europe (Setvak and Snow, 2003). Since the inaugural ECSS in 2002, a further two have been held and the 4th ECSS is scheduled to be held in Trieste in September 2007. The forthcoming conference is a joint initiative of the European Severe Storms Laboratory and the European Meteorological Society, devoted to all aspects of convective severe weather such as nowcasting, climate change, social and economic impacts of storms, *etc.* (Giaiotti, pers. comm., 2006).

Research in other parts of the world has not progressed at the same pace and has received far less attention from the international research community (Schmidlin and Ono, 1996). Recently, though, there has been a considerable awakening of interest in severe storms globally and research has focused on comparing tornado intensity/impact distributions in other areas of the world with Europe and the USA/Canada, in particular Argentina, Brazil, Australia, Soviet Union, Japan and South Africa (Brooks and Doswell III, 2001; Brooks *et al.*, 2003; Dotzek *et al.*, 2003; Brooks, 2004; Feuerstein *et al.*, 2005).

3.7.2 South Africa: background on severe storm incidence

Severe convective storms are a frequent occurrence in South Africa (Visser, 2001), yet account for far less human and economic losses compared with large-scale floods and droughts. It is suggested, however, that they still pose a considerable risk to local communities in South Africa on a small scale, due to their frequent, localised occurrence in time and space. As in other parts of the world, the major hazards associated with severe convective storms in South Africa are damaging winds, hail, flash floods and lightning. Tornadic thunderstorms are the most intense, yet least frequent of all severe storms in this country. Until fairly recently, a general public perception prevailed that severe convective storms with supercell characteristics (including tornadic thunderstorms) do not occur in South Africa (de Coning and Adam, 2000). Bryant (1991), van Heerden and Hurry (1992) and Tyson and Preston-Whyte (2000) assert that tornadoes are rare phenomena in South Africa. However, research findings over the past number of years point to an increasing number of reported severe storm occurrences over the past 10-15 years and this seems to have dispelled this erroneous perception (Visser, 2001).

D'Abreton (1991) collected data on tornado occurrence in South Africa from 1984 to 1991 and concludes that tornadoes in South Africa occur with greater frequency than is generally realised. Goliger *et al.* (1997) report that in excess of 200 tornadoes have occurred in South Africa since 1900, with the majority of occurrences in the eastern escarpment areas. Snow and Wyatt (1997) claim that South Africa is one of the top five countries with the highest number of reported cases. Importantly, Roberts and Sampson (1996) emphasise the high incidence of unreported cases, especially in remote rural areas of South Africa. During the last ten years a spate of severe tornado occurrences, including Harrismith (1998), Umtata (1998), Mount Ayliff (1999, the most severe tornado on record in South Africa) and Manenberg (1999) has sparked public interest and has engendered further research on severe storms in South Africa. The Eastern Cape, in particular, has experienced a larger than expected number of severe weather events (tornadoes and thunderstorms) in recent years. Perry (1995) reports that a severe convective storm which caused tremendous hail damage at Grahamstown in 1993 occurred outside the area of most frequent occurrence and exceeded in intensity any such storm in living memory in the area affected. Van Niekerk and Sampson (1999) report that seven tornadoes and three severe thunderstorms occurred during the 1998-1999 season in the Eastern Cape, causing damage estimated in excess of R102 million, 50 fatalities and hundreds of injuries. A study by Pyle *et al.* (1999) revealed that 27 reported tornadoes occurred in the Eastern Cape from 1900 to 1999, 20 of which occurred in the densely populated rural areas. In the light of this evidence it is suggested that South Africa and the Eastern Cape region does experience a much higher severe storm risk than has been previously reported. Research in this area is therefore a priority.

3.7.3 Local response: A review of South African research in the field

In the past, research in South Africa on climate hazards in general has focused on the impact of droughts and floods, for example Freeman (1984, 1988); Myburgh (1991); Vogel (1991, 1994); Adams (1993) and Mgquba (2002). It has been argued, however, that questions surrounding all natural hazards in South Africa need to be placed high on the research agenda for geographers (Vogel, 1992).

Various technical research efforts related to aspects of severe storms have in the past emanated from the SAWS, the CSIR and other parastatals, but have been limited in scope and comprise essentially the compilation of frequency/density maps for hail and lightning in South Africa (Schulze, 1965; Carte and Held, 1978; Olivier, 1988; Le Roux and Olivier, 1996; Schulze, 1997). The use of weather radar methods for severe storm identification has also formed the basis of some empirical studies in South Africa, e.g. Visser (1999, 2001). While these projects of a technical orientation do shed light on some temporal and spatial dimensions of severe storms, they are not rigorous, in-depth research dissertations based on sound hazard conceptual frameworks and recent methodologies.

During the last number of years in South Africa a spate of severe storms, particularly those in the Eastern Cape and KwaZulu-Natal, has encouraged seminal research into severe storms, which are incompletely understood and previously underestimated in this country. Various aspects have been researched, ranging from tornadogenesis and tornado climatology to human impact and risk assessments.

D'Abreton's (1991) study of tornadoes in South Africa may be seen as the first real attempt at scientific research into the synoptic characterisation of tornadoes in this country. Before 1991 the only research conducted on tornadoes and severe convective storms had been descriptive in nature, for example informal reports in South African Weather Service newsletters (d'Abreton, 1991). He examined the synoptic and mesoscale environments of four tornadoes which had occurred at Kokstad, Cedarville, Saldanha Bay and Welkom, and concluded that tornadoes in South Africa form under similar synoptic and thermodynamic conditions as those in North America. He suggests, too, that tornadoes occur with greater frequency than is generally realised, especially over the Natal interior. During a seven year period from 1984 to 1990 he found that there were 19 recorded cases of tornado formation, with an average of three per year during this time. Seven deaths, 117 injuries and extensive damage to property resulted from these events. Importantly, he points out that tornadoes probably occur more frequently than the data suggest, most likely as a result of poor reporting in sparsely inhabited areas.

Some years later, Goliger *et al* (1997) engaged in pioneering research on tornado frequencies and distribution patterns in South Africa for the period 1905 to 1996. Their research revealed that in excess of 200 reported tornadoes occurred in South Africa during this time, with the highest frequencies occurring over the eastern escarpment areas. They also compared the distribution of tornadoes with other severe storm phenomena (hail, thunderstorms and lightning) and population density. A tornado risk model for South African conditions, which has implications for building design, was also proposed. A tornado database, which was formerly maintained by the CSIR, was developed primarily from a SA Weather Bureau inventory of extreme weather events compiled by Viljoen (1987-1988) covering the period 1905 to 1987 and from a further Weather Bureau publication, CAELUM (1991): *A history of notable weather events in South Africa 1500-1990.* Unfortunately the responsibility of maintaining reliable statistics on tornado occurrences appears to have "slipped between two stools", with neither the CSIR nor the SAWS performing this role in any organised way today. Goliger *et al* *(*1997) emphasise the fact that the total of 200 tornadoes is not completely reliable as some of the tornadoes listed may have been severe thunderstorms, downbursts or tropical cyclones and *vice versa.* Incorrect and scanty reporting of severe storms remains a problem in South Africa (and in other countries) and may skew the statistics significantly. For example, it is estimated that only 15% of French tornadoes are being reported (Brooks and Doswell III, 2001). Interestingly, Brooks (pers. comm., 2005) is of the opinion that, compared with some other countries, South Africa does not fare too badly in terms of severe storm reporting and statistical reliability. Significantly, Goliger *et al.* (1997) make the point that at the time of their research, no statistical information was available on severe thunderstorms in general, as distinct from tornadoes, in South Africa.

Hundermark (1999) undertook a similar analysis of the distribution and frequency of tornadoes in the 20th Century in South Africa, using Geographical Information Systems (GIS) as a mapping and analysis tool. He suggested that there has been a shift in the timing and frequency of tornadic events during the five years from 1992-1996. Pyle *et al.* (1999) further expanded this work and examined the distribution of tornadoes in the Eastern Cape in relation to the spatial pattern of both urban centres and rural populations for the period 1900-1999. In addition, the authors examined the differential impact of selected tornadoes on urban and rural populations in the Eastern Cape. They suggest that although the cumulative cost is generally higher in urban areas due to highly developed infrastructure, recovery may be fairly rapid. In densely settled marginalised rural areas the absolute cost in monetary terms is lower, but the impact on individuals and communities is likely to be far greater.

Roberts and Sampson (1996) and van Niekerk and Sampson (1999) conducted detailed case studies on severe storm events in the Eastern Cape during 1996, 1998 and 1999 from both a climatological/meteorological and impact perspective. In particular, their research revealed that during the 1998-1999 season, seven of a reported ten occurrences were positively identified as tornadoes (three of the ten occurrences were re-classified as severe thunderstorms in the absence of any definite tornado indicators). Both van Niekerk and Sampson (1999) and de Coning and Adam (2000) warn that severe storms can be erroneously reported as tornadoes. Van Niekerk and Sampson (1999) conclude that there was a larger than expected number of severe weather events over the Eastern Cape during the 1998-1999 season. Of particular significance was the tornado which devastated rural villages in the Mount Ayliff/Tabankulu area in 1999, causing damage amounting to R3 million, 21 deaths and 357 injuries. This occurrence is reported to be the severest tornado on record in South Africa, measuring F4 on the Fujita-Pearson scale. The authors suggest that while the increase in severe storm incidences is somewhat exceptional for the period, increased awareness and reporting may be a greater factor in this increase. In conclusion, the authors recommend strongly that public awareness campaigns regarding severe storms be urgently implemented in the province, with special attention focused on remote and underprivileged communities, where loss of life is highest.

De Coning and Adam (2000) researched tornadic thunderstorm events during the 1998-1999 summer in South Africa, focusing on the Harrismith (1998), Umtata (1998) and Mount Ayliff (1999) tornadoes. Their analysis was primarily concerned with tornado climatology, in particular the meteorological and climatological conditions prevailing at the time of the events. The three events were measured against certain recognised threshold values or indicators for atmospheric instability and severe weather, *viz.* CAPE Lifted Index, Showalter Index, Total Totals Index, Sweat Index and wind shear. Their findings show that not all threshold values were met in the three events, suggesting that these indicators of severe weather and/or tornadoes are not completely reliable, yet may provide a valuable tool for forecasters. They warn that better forecasting of severe weather events needs to become a priority in this country. In addition, the authors emphasise the critical importance of real-time observations, in particular the use of upper-air soundings and weather radar data in monitoring the development of possible tornadic thunderstorms. Certain areas of the former Transkei region of the Eastern Cape, which are known to experience a high incidence of thunderstorm activity, were not covered adequately by the radar network in South Africa until the very recent installation of a new weather radar at Umtata. This previously poor radar coverage may have contributed to a lack of identification of tornadoes and hence a lack of data for the region. Martin (pers. comm., 1998) suggests that severe thunderstorms in the former Transkei may spawn significantly more tornadoes than those which are reported. D'Abreton's (1991) study of tornadoes in South Africa confirms the notion that tornadoes are more common than is generally believed in the area. He cites the KwaZulu-Natal region in particular as one of high tornado frequency. Considering that KwaZulu-Natal and the former Transkei border each other, it may be reasonable to assume that these two regions together may form a contiguous area of much higher tornado activity than has been believed previously.

Rouault *et al.* (2002) examined the possible influence of the Agulhas current on extreme weather events. They suggest that anomalously high sea-surface temperatures (SSTs) along the Agulhas current for the period 14-15 December 1998 played a significant role in the formation of the Hogsback and Umtata tornadoes during that time. They argue that a temporary rise in SSTs allowed for the formation of a very intense latent heat flux above the Agulhas current, which in turn caused a low-level advection of moisture onshore and local intensification of the storm system inland. Significantly, the authors believe that the contribution of moisture from the Agulhas current to the development of the storm may have been greater than their analyses suggest. Van Niekerk (pers. comm., 2006) suggests that the undercutting provided by the low-level advection of moisture is a critical ingredient in the formation of destructive tornadoes in the north-eastern areas of the province. Radar observations of storm cell development show that tornadoes are more likely to form if the cells track in a 'deviant motion' from the south-west to the north-east, compared with the normal south-easterly drift of storms in the Eastern Cape (van Niekerk, pers. comm., 2006).

Research on the social aspects of severe storms in South Africa has been scant. A search for studies in this field revealed only three, *viz.* those undertaken by Mgquba (1999) on Eastern Cape tornadoes and by Cozett (2000) and Nomdo (2005) on the Manenberg tornado.

Mgquba (1999) investigated people's perception of and vulnerability to tornado occurrences in the rural Ngqamakwe-Idutwya region of the Eastern Cape. Her study revealed, in particular, the interdependence of tornado risk and human vulnerability. In addition, it highlighted the importance of implementing proactive disaster management plans in building resilience amongst marginalised, poor rural populations in the Eastern Cape. She warns that before undertaking risk and vulnerability assessments, it is crucially important to understand the way in which communities perceive and understand their natural environment and the meaning attached to it. She suggests that folklore and the supernatural world, rooted in complex cultural backgrounds, still plays a major part in the perception of severe weather events among certain rural communities in the Eastern

Cape. This is evidenced, for example, in the local name of “Inkanyamba”, meaning a snake, which is given to tornadoes in the region. The word does not only refer to a climatic phenomenon, but embodies a tornado spirit (Wood, 2000). It is believed that traditional healers and those wanting to acquire wealth use the “snake” to gain certain powers. If the master of the snake upsets it in any way, it becomes angry and will unleash its anger in the form of a violent storm (tornado). Interestingly, “Inkanyamba” is associated with water and disappears over large and deep bodies of water, looking for its partner (Wood, 2000). Oral tradition and anecdotal evidence suggest that tornadoes are not something new to the Eastern Cape, with reports dating back to 1943 in the Hogsback area (Wood, 2000).

Mgquba’s (1999) research also revealed that the more educated members of the communities in the area had a scientific understanding of tornadoes, albeit somewhat limited. Teachers and students she interviewed understood tornadoes in terms of very powerful storms, but lacked any further understanding on the specific nature and causes of tornadoes. These findings, although on a limited scale, indicate the imperative for assessing indigenous knowledge and local perceptions of severe storms in rural areas. Education and disaster planning initiatives must try to bridge this local knowledge with scientific/expert knowledge (Wisner, 1995).

Cozett (2000) investigated the 1999 Manenberg (Cape Flats) tornado from the perspective of community displacement and temporary housing. A total of 1 606 families were affected and 659 families were displaced by the event (Goliger and de Coning, 1999). Cozett’s (2000) study revealed that human vulnerability to extreme weather events played a major role in the disaster. He suggests that poor infrastructure and sub-standard housing of the inhabitants of Manenberg precipitated the disaster. He contends that the disaster was no “Act of God” but was in fact brought about by the extreme vulnerability of inhabitants living in poverty-stricken conditions. He ascribes these living conditions to the “remnants of the apartheid era” (Cozett, 2000; 29). Similarly, Nomdo’s (2005) study on the Manenberg severe storm examined the role of women in informal settlements and how they draw on networks and relationships in managing adversity.

The growing problem of vulnerability, risk and sustainable development in relation to disasters in South Africa is the focus of the University of Cape Town's Disaster Mitigation for Sustainable Livelihoods Programme (DiMP). The programme's mission is to promote disaster mitigation as one strategy for sustainable development in southern Africa. Currently DiMP is running two major projects: *Periperi* and *Mandisa.*

Periperi ("partners enhancing resilience for people exposed to risks") is a network of partners committed to risk reduction in Southern Africa. *Periperi's* most important mission is to reduce the impact of natural and other threats in communities at risk (DiMP, 2001). More recently, *Periperi U* has been formed as a platform for university partnership to reduce disaster risk in Africa. At this stage four key universities from South Africa, Ethiopia, and Tanzania form this partnership (Holloway, 2006).

Mandisa ("monitoring, mapping and analysis of disaster incidents in South Africa") is a research initiative aimed at consolidating years of recurrent disaster incidents in the Cape Metropolitan Area, as a pilot study. In addition to newspapers, numerous data sources are used in order to capture not only the high impact, large-scale events, but also the highly recurrent small-scale events that occur in the metropolitan informal settlements (UNDP, 2004). In the future the programme hopes to extend its scope to cover the whole of the Western Cape. The aim is to provide a planning tool for various agencies for disaster mitigation and sustainable development in South Africa (DiMP, 2001).

Furthermore, DiMP has engaged in seminal research into the socio-economic and environmental impacts of severe weather events in the Western Cape Province of South Africa, particularly urban and peri-urban flooding events (*vide* section 3.7.4.2 of this chapter) and informal settlement fires in the Cape Town metropolitan area.

Similarly, the African Centre for Disaster Studies (ACDS) was established in 2002 at North-West University in Potchefstroom. The explicit aim of the ACDS is to "address the need for world-class training, education and research in disaster related activities within southern Africa and the wider African context" (ACDS, 2005). The focus is on offering training courses to practitioners on aspects of disaster risk management, while research activities appear to be limited at present. The most recent initiative in South Africa is the formation of a specialist unit at the University of the Witwatersrand in Johannesburg in 2006 called reVAMP (re Vulnerability, Adaptation and Mitigation Planning) which, amongst other applied research concerns, focuses on rural vulnerability and food security issues in southern Africa.

3.7.4 A review of recent frameworks and methodologies in severe storm and hazards research

Whilst not negating the importance of technical investigations into the climatology and physical characteristics of severe storms which have been researched exhaustively by climatologists and meteorologists for decades, the researcher asserts that a more holistic, integrating hazards framework is best suited to a detailed in-depth study of severe storm hazard in the Eastern Cape. Hazard methodologies and research frameworks can be best viewed as a continuum from the early deterministic, physical natural hazard frameworks to the more recent ones which emphasise social vulnerability as the causal factor in disasters (Wisner *et al.*, 2004).

More recently formulated conceptual models and hazard frameworks, such as those proposed by Blaikie *et al*. (1994), Cutter (1996), Tobin and Montz (1997) and Wisner *et al.* (2004), are particularly useful in uncovering important contextual factors and "root causes" of vulnerability – not only the physical characteristics of hazards. Other authors have taken this conceptualisation even further and have placed the concept of sustainable livelihoods at the centre of disaster vulnerability (Twigg, 2001). In this approach, vulnerability, in all its forms, is considered as an integral part of the context in which poor people's livelihoods are shaped (Twigg, 2001).

3.7.4.1 International

Significantly, internationally there appear to be very few detailed, sustained studies conducted in the field of severe storm research using the integrating conceptual models and frameworks discussed above. Most studies are either predominantly climatological/technical in nature or otherwise more sociological/anthropological. Empirical studies bridging the gap between the two research foci seem to be few, although better integrated, interdisciplinary studies is exactly what authors argue for (Alexander, 1993; Tobin and Montz, 1997; ISDR, 2004).

Given the plethora of short papers covering virtually all aspects of severe storms in the USA/Canada and the UK and Europe, it is impossible to review every research approach/methodology used in each study. It is useful, however, to classify them into broad categories based on the methodologies employed and to illustrate these with a few empirical studies.

The first category encompasses a wide range of methods used predominantly by disaster sociologists such as Quarantelli and Dynes (1976) and are related to gauging community perceptions, public responses to warnings, coping/survival mechanisms, risk factors, *etc.* Generally, a specific or comparative case study approach is employed, using methods such as surveys, interviews, questionnaires, field evaluations, statistical tests, *etc.*, for example *Risk Factors for Death in the 22-23 February 1998 Florida Tornadoes* (Schmidlin *et al.,* 1998), *Survival Mechanisms to Cope with the 1996 Tornado in Tangail, Bangladesh: A Case Study* (Paul, 1997) and *Warning Response and Risk Behaviour in the Oak Grove-Birmingham, Alabama, Tornado of 08 April 1998* (Legates and Biddle, 1999).

Secondly, impact studies focusing on the human, economic and environmental consequences of severe storms are common in the literature. Examples of such studies are *Funnel Fury* (Lanken, 1996), which examines the human and economic impact of tornadoes in Canada, *Deaths and injuries caused by lightning in the United Kingdom: analyses of two databases* (Elsom, 2001) and *Societal impacts of severe thunderstorms and tornadoes: lessons learned and implications for Europe* (Doswell III, 2003).

Thirdly, several studies have been made from an inventory/chronology/historical event reconstruction perspective, for example, *Tornadoes in Ireland: an historical and empirical approach* (Tyrrell, 2001), *A developing inventory of tornadoes in France* (Paul, 2001) and *Tornadoes within the Czech Republic: from early medieval chronicles to the "internet society"* (Setvak *et al.*, 2003).

Fourthly, and perhaps most common in the literature, are those studies conducted from a physical, technical and climatological perspective. Such studies tend to be of a highly technical nature and are aimed at professional, operational forecasters, climatologists and meteorologists. Examples include *Survey of convective supercell in Slovenia with validation of operational model forecasts* (Gregoric *et al.,* 2003), *Evaluating the sounding instability with the Lifted Parcel Theory* (Manzato and Morgan, 2003) and *Using short-range forecasts for predicting severe weather events* (Stensrud, 2001).

Lastly, some researchers have employed on a more statistical approach to determining climatological hazard and risk. Such efforts attempt to quantify/model risk by using measures such as statistical return periods of severe events, for example, *Statistical modelling of tornado intensity distributions* (Dotzek *et al.*, 2003), *Return periods of severe hailfalls computed from hailpad data* (Fraile *et al.*, 2003) and *Climatological risk of strong and violent tornadoes in the United States* (Concannon *et al.,* 2000).

An important development in the last 20 years has been the use of technology, in particular GIS, remote sensing, spatial modelling systems and simulations. These tools have become fundamental components of recent hazards research, particularly in vulnerability/risk assessments (Wadge *et al.*, 1993; Tobin and Montz, 2004). GIS has also become a valuable tool used by disaster management practitioners in minimising the risk of disaster (Kotze, 2001). Modern techniques have allowed a broader view of hazard and risk and have facilitated a more detailed analysis of the complex interactions at work in defining the hazardousness of locations (Tobin and Montz, 2004; ISDR, 2004). In addition, GIS allows working with larger databases and the examination of risk and vulnerability arising from multiple hazards, for example Montz's (1994) examination of multiple hazards at Rotorua, New Zealand. The use of GIS to represent hazard, risk and vulnerability spatially has become an accepted and valuable research approach, for example Cutter *et al.'s* (1999) seminal work on mapping environmental risks and hazards in South Carolina, and the production of multi-hazard risk maps for Cairns, Australia (ISDR, 2004). Recent efforts internationally have been made to include various socio-economic indices, such as the Human Development Index (HDI) and Disaster Risk Index (DRI) into GIS risk mapping and in the development of multi-hazard models (UNDP, 2004).

While the benefits of the use of modern technology in hazards research are worth noting, in particular the developments in computerised hazard mapping, there are several constraining factors and *caveats* which have been raised by authors. Firstly, while much research has focused on mapping the physical aspects of vulnerability, the inclusion of social, economic and environmental variables into GIS models remains problematic (ISDR, 2004). These indicators are not always readily obtainable in least developed countries or are not easily quantifiable and rely on subjective assessments such as the active involvement of communities at risk (ISDR, 2004). Carrara *et al.* (1999) argue that the assumption that the use of GIS leads to the production of risk maps which are more accurate, credible, objective and unbiased than conventionally hand-drawn ones is erroneous. Tobin and Montz (2004) warn, too, that over-dependence on the use of technology may over-simplify reality and provide a new false sense of security which may in fact be counter-productive in the long term.

The aforementioned research projects and methods employed are useful as they approach the severe storm research field from different perspectives. It is suggested that combination or particular amalgam of the methods discussed above would prove useful in a study of Eastern Cape severe storm hazard.

3.7.4.2 South Africa

In South Africa, the paucity of detailed studies on severe storm/climate hazards makes it difficult to compare, analyse and synthesise different research frameworks and methodologies which have been used in a local context. However, for comparative purposes, the few studies undertaken may be grouped into two broad categories based on approach and methodology: sociological/anthropological and physical/climatological. It is important to note that studies undertaken from a sociological/anthropological perspective do not entirely preclude methods used in a physical/climatological perspective and *vice versa.* The following analysis intends to show a general research orientation.

The first category includes studies on severe convective storms in the Eastern and Western Cape by Mgquba (1999), Cozett (2000) and Nomdo (2005) and on flood hazard in KwaZulu-Natal and Gauteng by Ferreira (1990), Maphanga (1997) and Mgquba (2002). Techniques commonly used are interviews, surveys, field research, participant observation, participatory rural appraisal (PRA) and historical/archival research. Clearly the research methods in these studies are appropriate to the main objective, which is to investigate how the complex interrelationships amongst social, political and institutional "underlying" factors play a role in increasing the vulnerability to disasters of poor populations living in marginal environments. These studies are sound empirical studies using aspects of vulnerability research frameworks proposed by modern theorists such as Blaikie *et al*. (1994) and Wisner *et al*. (2004), yet do not emphasise to any great degree any of the physical factors at work. Importantly, the studies listed above by Mgquba (1999), *etc*. are at either Honours or Masters research level, which lends some academic rigour and credibility to their work; other work in the field is not always academic.

The second group encompasses studies by d'Abreton (1991), Perry (1995), Goliger *et al.* (1997), Hundermark (1999), Pyle *et al.* (1999), van Niekerk and Sampson (1999), de Coning and Adam (2000) and Rouault *et al.* (2002). These studies vary in depth and scope, yet have certain commonalities in terms of research orientation and methodology; they are essentially short research papers examining various physical, climatological and spatial-temporal characteristics of severe storms in South Africa. Standard methods include the statistical formulation and interrogation of databases, mapping (including the use of GIS), measurement of instability/severe storm indices, correlation between SSTs and other climate parameters, *etc.* Such quantitative methods place these studies closer towards the physicalist/naturalist pole of the hazards research continuum.

While not strictly falling within the ambit of "severe convective storm" research as defined in this study, three studies undertaken in this country within the broad field of climate hazards are illuminating and instructive in terms of research methodologies used; all attempt to integrate the human and physical aspects of hazard in a more balanced way in their research frameworks. Therefore, these studies provide valuable guidelines for formulating a similar integrating, holistic and balanced research framework for investigating severe storm hazard in the Eastern Cape.

Firstly, Myburgh (1991) conducted doctoral research on the drought and flood hazard in the arid and semi-arid regions of the Cape Province. The focus of the thesis was to identify the range of human adjustments and adaptations to the hazard. He examined the spatial patterns of drought and flood hazard, devised a method for quantifying flood hazard and assessed the role humans might have played in increasing the level of hazard by modifying their environment. Questionnaires gauged the coping and adjustment measures used by farmers in the area. Explanations for the response behaviour were found in individual perception of the hazard, and in a variety of other socio-economic and political factors. Clearly, this research was a pioneering attempt to break away from the traditional perspective of researching the purely physical aspects of droughts and floods, which have been better documented in this country. By using an integrating hazards framework, Myburgh was able to explore the physical, behavioural and social aspects of flood and drought hazard in order to gain a more insightful understanding of the complex interrelationships at play in defining the hazardousness of the region. In this respect it is suggested that his research represents a landmark study in this country.

Secondly, Mgquba's MSc thesis (2002) examined the physical and human dimensions of flood risk in Alexandra Township, Johannesburg. Using an adaptation of the "pressure and release" model proposed by Blaikie *et al*. (1994), the case study of severe flooding of the Jukskei River in Alexandra Township uncovered a host of root causes, dynamic pressures and unsafe conditions, which heightened the vulnerability and associated risk of poor local communities living in the floodplain. The impact of the floods was seen to be a result of the complex interplay of both social and physical factors in defining patterns of risk. Importantly, the use of a research framework which emphasised the vulnerability component in disasters, yet did not negate the influence of physical factors, allowed the researcher to gain a deeper and more comprehensive understanding of flood risk in the area.

Thirdly, the Disaster Mitigation for Sustainable Livelihoods Programme at the University of Cape Town co-ordinated a multi-disciplinary research team to investigate the March 2003 cut-off low flood event in the Boland-Overberg districts of the Western Cape (DiMP, 2003). A hazards/risk reduction conceptual framework, focusing on the interplay between natural or other threats and conditions of socio-economic, environmental or infrastructural vulnerability, was found to be best suited to this study. In this study "hazard" or "trigger" is identified as the cut-off-low weather system, associated heavy rain, strong coastal winds and cold temperatures. On the other hand, "vulnerability" is seen as incorporating characteristics which are likely to increase the probability of loss with regard to river systems, agriculture, physical infrastructure, services, human well-being and health. The study aimed to illustrate how the interrelationships between the physical aspects of the hazard, the patterns of social vulnerability and the role of intervening institutions in the disaster define differential patterns of risk. The methods used in the study included a wide range of data-collection, fieldwork and consolidation. Specialists in various areas such as climatology, flood hydrology, disaster management and vulnerability/risk assessment were required to compile sections of the report, yet inter-disciplinary collaboration was essential to prevent the report from being fragmented; this was essential to provide an overall holistic synthesis of the event.

An important aspect of the flood event study was the documentation, recording, mapping and analysis of recorded losses and impacts. To facilitate this, a GIS was used to manipulate the data and to map the spatial distribution of disaster impacts. A differential impact pattern was evident, which indicated that specific elements were vulnerable to different aspects of the range of hazards associated with the flood event. Difficulties encountered in this process related to the collection of impact information, duplication and the imprecise nature of impact reports, and the possible omission of reports captured in the database.

Limitations to the research included the difficulty of consulting all those involved in the disaster, incomplete geographic coverage of all affected areas, not only those formally declared as “disaster areas”, a lack of baseline socio-economic data for the whole area and the uneven management of incident recording/tracking documentation.

Notwithstanding these limitations and possible weaknesses, the report does succeed in providing a sound framework for investigating a climate disaster incident from a hazard, vulnerability and risk perspective. The authors also suggest that the methodology employed in this study may be used as a general guide in other post-disaster assessments. Considerable international interest has been shown in the report since its publication, particularly in respect of the embracing research methodology used (Holloway, pers. comm., 2005).

The researcher has found a number of aspects of the methodology used in the report to be valuable in formulating a research methodology for this study. Significantly, the report “uncovered” a number of vulnerability issues and institutional weaknesses and gaps in dealing with disaster incidents of this kind in the Western Cape, which may not have been revealed had a more traditional approach been used, focusing purely on the physical aspects of the disaster. Landmark recommendations arising from the study include the:

1. strengthening of institutional capacities to anticipate and to disseminate weather warnings
2. strengthening of institutional capabilities for more effective emergency responses and post-event recovery processes
3. adoption of immediate strategies and measures to strengthen institutional capacities in disaster management
4. strengthening of capacities to record and track disaster-related impacts to better inform disaster management and development planning

The aforementioned points are to be seen in the context of the recommendations made in the Disaster Management Act (2002) and the Framework (2005). The new legislation stresses the urgent need for strengthened capabilities in disaster management, with the emphasis on disaster prevention and mitigation; these shortcomings are clearly borne out in the empirical findings of the cut-off low case study.

The following chapter discusses the Act and Framework within the context of international and national disaster management developments.

3.8 Summary

This chapter has provided an overview of the main aspects of climate hazards from a theoretical, contextual and research perspective. It has been shown that the multi-faceted nature of climate hazards has led to a number of conceptual debates. Importantly, too, this chapter has highlighted the dearth of climate and severe storm related research undertaken from a hazards perspective, both internationally and nationally. Nonetheless, certain key studies that have been undertaken on recent severe weather events using a hazards-vulnerability-risk framework are instructive and have provided important guidelines for this study.

CHAPTER FOUR: DISASTER RISK MANAGEMENT: INTERNATIONAL, AFRICAN AND SOUTH AFRICAN DEVELOPMENTS

> *Approaches in disaster reduction have become much more complex and emphasis has shifted from relief to mitigation.*
>
> Thywissen, 2006; 10

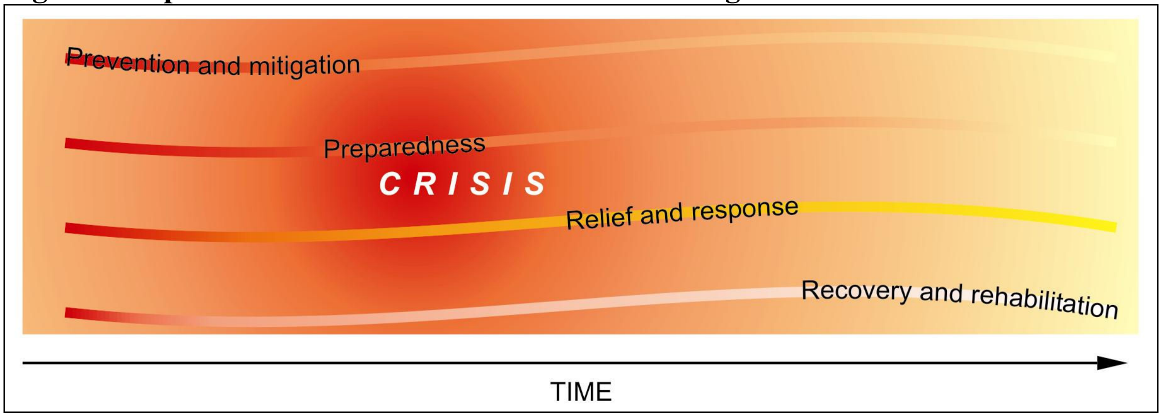
4.1 Introduction

Chapter Three has highlighted the need for climate impact research that is approached from a hazard-vulnerability-risk reduction perspective. The purpose of this chapter is to provide a critical overview of recent developments in disaster *risk* management, both internationally and locally.

4.2 International context and trends

The principles of disaster prevention, preparedness, mitigation and sustainable development are integral to recent disaster management initiatives. This approach to managing disasters is in contrast to the earlier approaches, which focused almost exclusively on relief measures and recovery. Alexander (1999) terms this the "biscuits and blankets" approach, which he criticises as a method of entrenching dependency on the state for all future disasters. Jegillos (1999) distinguishes between previous 'emergency management' approaches to dealing with disasters and more recent shifts toward a developmental approach, focusing on mitigation and reduction of vulnerability in communities. Modern disaster *risk management* strategy has as its objective to build capacity to manage and reduce risks related to disasters (Jegillos, 1999; Thywissen, 2006). This conceptualisation is shown in the expand-stretch model (Figure 9), where disaster risk management is viewed as a continuous and dynamic process, rather than the more traditional conceptualisation of a defined sequence of actions from prevention to recovery (Holloway, 2003).

Figure 9 Expand-stretch model of disaster risk management



Source: Adapted from RSA, 1999; 32

Current international thinking on disaster management emphasises the need for investment in proactive measures which replace more dated reactive measures. Disasters, according to recent thinking, are not unpredictable and random acts of nature, but rather are the results of poorly managed 'everyday risk' (Vogel, 1998b). A strong developmental focus to disaster management emerged internationally, which was seen as a more effective means of mitigating risk (RSA, 1998; Yodmani, 2001; Holloway, 2003). Countries which were forerunners in this paradigm shift include Australia, the USA and parts of South America, Central America and Southeast Asia (Jegillos, 1999; Salter, 1999; ISDR, 2004). For example, the framework adopted by Australia's National Emergency Management Committee in 1996 emphasises risk management, the involvement of all stakeholders, formation of partnerships and planning/communicating with communities (Salter, 1999). Internationally, there was a growing recognition of the fundamental link between disasters and sustainable development (ISDR, 2004). Governments realised the need to fund long-term prevention and risk-reduction measures rather than short-term repeated relief responses, which are expensive and not sustainable in the long term (RSA, 1999; Fara, 2000; Karimanzira, 1999).

A number of international trends in disaster management are discernible. Firstly, indigenous and scientific knowledge and literature on hazards and risks has increased considerably, allowing for more accurate assessment, tracking and forecasting of disaster events. In particular, improved flow of information and better community interaction has greatly improved the understanding of and response to early warning signals, allowing for timeous interventions. Secondly, there has been a preoccupation with rare large-scale disaster events which capture the attention of the world media. There is a realisation, however, that smaller scale local events can be equally devastating for small communities and that disaster management plans must seek ways of focusing on both large-scale and small scale events (Alexander, 1999; ISDR, 2004). Thirdly, there has been a more inclusive involvement of all stakeholders and practitioners in disaster management efforts and the formation of co-operative partnerships between the state, private sector, NGOs, policy makers and specialists, *etc.* In this way risk reduction and disaster management are seen as multi-disciplinary processes (RSA, 1998; RSA, 1999; Jeggle, 2001).

4.3 African and South African developments

The African continent is highly susceptible to disasters, yet the traditional reactive response to disasters persisted in most countries, lagging behind developments internationally (ISDR, 2004). Focusing on southern Africa, Holloway (2003) cites a number of reasons for this, in particular poverty, under-development, political instability and relationships based on dependency and patronage with the rest of the world. The "externalisation of disaster response" (Holloway, 2003; 3) had the effect of discouraging ownership of disaster risk by African countries and of entrenching dependency on outside assistance during times of crisis. Alexander (1999) adds that increasing vulnerability and civil unrest will become an inevitable product of a lack of natural disaster reduction plans in national policies on the continent.

More recently, however, shifts toward a more proactive disaster risk management have become evident in some African countries, in particular those that have been repeatedly affected by recurring droughts and floods, *viz.* Ethiopia, Kenya, Mozambique and South Africa (ISDR, 2004). A significant development in recent years has been the development of an African regional strategy for disaster risk reduction, where the aim is to "contribute to the sustainable development and poverty eradication by facilitating the integration of disaster risk into development" (AU/NEPAD, 2004; 2). A number of disaster risk training programmes have been implemented at universities in east African countries , e.g. a specialised undergraduate degree in disaster risk management is offered at Bahir Dar University in Ethiopia and a Disaster Management Training Centre has been operating for some time at the University College of Lands and Architectural Studies in Dar Es Salaam in Tanzania (ISDR, 2006). In South Africa, university level disaster risk management training is offered at DiMP at the University of Cape Town, the ACDS at North-West University in Potchefstroom (*vide* Chapter 3, section 3.7.3) and at the Disaster Risk Management Training and Education Centre for Africa (DiMTEC) at the University of the Free State in Bloemfontein. Research in the field of disaster risk management has gained momentum in Africa lately and in 2005 the international ProVention consortium awarded 13 grants to enable emerging risk researchers from African and Middle Eastern countries to study disaster risks in their own countries (Holloway, 2006).

In keeping with international developments, the wheels were set in motion to develop a more enlightened disaster management policy in South Africa. Vogel (1998a) refers to earlier responses to disaster management as "crisis-management" responses; until very recently South Africa had no official national or regional disaster management plan or strategy. Actions were reactive rather than proactive with very little emphasis on prevention and risk reduction (RSA, 1994; Karimanzira, 1999). Vogel (1998a) highlights this lack of a proactive disaster policy and strategy, citing the profound impact of disasters on the poor and vulnerable and the associated loss of livelihoods, in particular. The Civil Protection Act No 67 of 1977 gave power to the minister of Provincial Affairs and Constitutional development to declare a "state of disaster" but did not give further instructions on what actions were to be taken or any clear responsibilities regarding decision making (RSA, 1999). This Act, however, focused entirely on post-disaster response and recovery, neglected all aspects of prevention and risk reduction and did not allow for inclusive participation by all relevant stakeholders (DiMP, 2003). Other legislation, primarily focusing on agriculture, allowed for further aspects of disaster management to be invoked at various state and departmental levels, yet in an uncoordinated and fragmented manner: Water Act, 1956, Agriculture Credit Act, 1966, Fund Raising Act, 1978, Agricultural Pests Act, 1983, Conservation of Agricultural

Resources Act, 1983, Agriculture Development Fund Act, 1993, Agriculture Financing Act, 1993. Private organisations and NGOs played valuable relief roles, too, yet in an *ad hoc*, uncoordinated manner. Vogel (1998a) criticises previous disaster interventions in this country as ignoring poor, vulnerable communities and as favouring commercial White farmers. Thus, a pressing need existed for a streamlined, coordinated and unified disaster management policy based soundly on the principles of prevention and risk reduction.

Since the 1990s perspectives on disaster management in South Africa began to undergo a substantial shift. Vogel (1998a and 1998b) identifies the main factors contributing to this change and providing impetus for reform: the serious drought at the time, repeated disaster occurrences in later years such as the Ladysmith floods in 1994 and 1996, the Cape Flats Flood of 1994, the Merrispruit slimes dam collapse of 1994, the efforts of a South African National Drought Consultative Forum and the preparation of the IDNDR contribution from South Africa. The meteorological droughts of 1982/83 and 1992/93 were the most severe during the 20th Century in South Africa. It was estimated that 70% of the national crop failed during the 1992/93 drought. Severe socio-economic consequences for poor, vulnerable communities resulted, such as malnutrition and other health problems. Importantly, drought management policy was brought under the spotlight and weaknesses revealed, in particular the lack of early warning systems and a comprehensive policy which included protection of vulnerable rural communities (RSA, 1994; Vogel 1998b). In response to this, a South African National Consultative Forum on Drought was formed to address the drought crisis, represented by the government, civil society, NGOs and political parties. An important result of this forum was the realisation that future strategies need to be proactive, based soundly on a long-term development approach aimed at improving community infrastructures and resilience (RSA, 1994). As an outcome of these realisations, government relief during the mid-1990s during times of drought was widened to include emerging, small scale farmers, whereas previously commercial White farmers received almost exclusive state support (Vogel, 1998b).

In addition to these initiatives to improve drought management during the 1990s, the Department of Water Affairs and Forestry instituted the preparation of a revised National Flood Management Policy in 1989, following the severe floods in 1987/88. Contained in the revised policy were the principles of preparedness, mitigation and early warning (RSA, 1994).

In 1995, in response to Cabinet calling for a review of disaster management structures and for the formulation of a better coordinated policy, an executive disaster management committee was formed with a range of working groups examining various types of disaster. In 1996, the National Disaster Management Committee was constituted to act as a coordinating and managing body. A year later in 1997 an Inter-Ministerial Committee for Disaster Management (IMC) was formed and a task team was given the mandate to begin drafting a Green Paper on Disaster Management (Vogel, 1998b; RSA, 1998).

The aim of the Green Paper, published by the Department of Constitutional Development in 1998, was to "ensure that an effective disaster management system is realised and implemented by way of national policy which will be reflected in the White Paper" (RSA, 1998; 4). The Green Paper acknowledged that former strategies to cope with the effects of disasters were inadequate and that a clear policy on risk reduction and proactive management was urgently required. Invitations from all stakeholders were invited to comment on the Paper, which was in essence an enlightened work resting firmly on the principles of prevention, mitigation and risk reduction from a developmental perspective. Clearly an emerging paradigm shift from "emergency management" to "disaster risk management" was discernible in the proactive focus of the paper. Key concepts such as development planning (within the context of the government's Reconstruction and Development Programme and the Growth, Employment and Redistribution strategy), mitigation, vulnerability and community involvement were integral to the recommendations made in the Paper.

The ensuing White Paper, as a policy document, was published in 1999, outlining the government's "new thinking" in relation to disaster management and setting forth an ambitious plan to deal with disasters in a developmental, preventative way. Particular attention was focused on the needs of those living in poor and vulnerable communities in both urban and rural areas (RSA, 1999). Seven key proposals, aimed at formulating a coherent national framework, were set out:

1. the integration of risk reduction strategies into development initiatives
2. the development of a strategy to reduce the vulnerability of South Africans
3. the establishment of a National Disaster Management Centre
4. the introduction of a new disaster management funding system
5. the introduction of a new Disaster Management Act
6. the establishment of a framework to enable communities to be informed and self-reliant
7. the establishment of a framework for coordinating and strengthening training and community awareness initiatives

The Paper called for a new two-pronged developmental approach, firstly to "strengthen capacity to track, collate, monitor and disseminate information and activities known to trigger disaster events", and secondly to "increase commitment to prevention and mitigation actions that will reduce the probability and severity of disaster events" (RSA, 1999; 23).

The Paper can be seen as a laudable attempt to deal with disasters in a more scientific, informed and critical manner, in line with current international thinking on disaster risk management. While one must see this as an attempt to draft policy within the context of international "best practice", a multitude of serious challenges to the actual implementation of the policy in South Africa were not fully addressed in the Paper, which must be noted as a shortcoming. Much of the Paper is devoted to acknowledging shortcomings in the current policy on disaster management, yet there is insufficient detail on tangible methods to overcome real and potential obstacles in implementing the policy. There is a sense in the Paper that the implementation of a new policy, while not without obstacles, can be expedited reasonably quickly and this is perhaps misguided given the major paradigm shift in policy and resultant changes in thinking about disasters required by all stakeholders. What is recommended in the paper is nothing short of revolutionary, requiring a huge mental shift from entrenched reactive “quick-fix” mechanisms to proactive, preventative ones. This may not be easy to attain in a short space of time.

Ensuing from this, the National Disaster Management Act of South Africa (No.57 of 2002) was promulgated in January 2003, as a culmination of more than seven years effort and collaboration. It is regarded as one of the most forward thinking pieces of disaster management legislation in southern Africa, replacing its precursor, the Civil Protection Act of 1977 (DiMP, 2003). It incorporates much of the proposed policy outlined in the White Paper and provides for:

1. an integrated and coordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery
2. the establishment of national, provincial and municipal disaster management centres
3. disaster management volunteers
4. matters incidental thereto

(Disaster Management Act, 2002)

A core feature of the Act is the establishment of a National Disaster Management Centre, as well as provincial and local disaster management centres. In addition, a critical aspect is the formulation of disaster management plans at the provincial and municipal level. Such plans must be integrated into provincial development planning and local municipal Integrated Development Plans (IDPs). Disaster and risk management must be incorporated into each phase of municipal IDPs (ISDR, 2004). Provinces must identify areas or communities at risk and are obliged to carry out risk/vulnerability assessments on a broad provincial basis and at a more detailed local level.

This legislation makes establishment of the following intergovernmental structures and policy frameworks mandatory: an intergovernmental committee on disaster management, a national disaster management advisory forum and a national disaster management framework. The Act stipulates that the framework needs to guide the development and implementation of disaster management envisaged by the Act.

Disaster prevention and mitigation is the main driver in the Act, focusing heavily on proactive measures that attempt to ameliorate the impact of small to large-scale events. Implementation of the Act has, as expected, been retarded by a few factors. Mgquba and Vogel (2004) argue that the implementation of a risk reduction approach will take some time to be realised given the complex nature of disasters and the associated cumulative risks. They emphasise that a more sensitive understanding of local context is required for effective disaster mitigation and that there is a lack of recognition of the types of interventions that are appropriate in terms of the Act. A further factor that has slowed the implementation is that for a period of time, following the promulgation of the Act in January 2003, certain sections of the old Civil Protection Act remained in force and disaster management was for a while "caught between two Acts" (DiMP, 2003). Provinces were expected to abide by certain sections of the old Act, yet needed to begin to implement certain aspects of the new Act that were not in conflict with existing legislation. Some provinces did, however, take the lead and succeeded in making significant progress by implementing aspects of the new Act into local Integrated Development Plans, as set out in the Municipal Systems Act of 2000 (DiMP, 2003).

A proposed national disaster management framework was published in May 2004, calling for public comment. The framework is the legal instrument specified by the Act to address the need for consistency across multiple interest groups and gives priority to developmental measures, disaster prevention and mitigation. The proposed framework was revised in response to public comment and a final version was gazetted in 2005. The framework comprises four key performance areas, each informed by specified objectives and key performance indicators to guide and monitor its implementation (RSA, 2005). The four key performance areas focus on: institutional arrangements; disaster risk assessment and monitoring; disaster risk reduction and disaster response; and recovery and rehabilitation. In addition three "enablers" are set out to attain the objectives: information management and communication; education, training, public awareness and research; and funding arrangements. Of note is the emphasis given to developing a strategic disaster risk research agenda at a national level and the participation of local research institutions is encouraging, given the low priority given to disaster research in southern Africa historically (Alexander, 2001; Holloway, 2003). The framework is comprehensive and thorough in dealing with all aspects of implementation and provides a useful tool for provinces to use as a guideline for implementation. One must remember that while legislation can set standards and boundaries for action, it cannot on its own bring about change; constant monitoring, policing and enforcing will be required for success (UNDP, 2004). It is, however, a formidable document, given the enormity of the proposed arrangements and new structures needed at national, provincial and local level. What strikes one immediately is the increased level of expertise and the amount of training/re-training needed to implement such policy, which is essentially a complete departure from the accepted and perhaps easier to manage reactive emergency management approaches, which are still entrenched at many levels of government (Mgquba and Vogel, 2004). In a sense this document sets out an ideal, an example of "international best practice", which is perhaps not entirely realistic, given the not insignificant obstacles it faces. Encouragingly though, this does allow South Africa, and to a lesser degree other contiguous southern African countries, to take greater responsibility for their own disaster risk by breaking the shackles of dependency on overseas countries for assistance during disaster events (Holloway, 2003).

The National Disaster Management Centre in Pretoria was formally established in 2006, together with the appointment of a new Head and senior staff. The Centre is currently pursuing a number of national and provincial initiatives in an attempt to hasten the process of implementation of the Act and Framework. These include: piloting vulnerability mapping in selected rural nodes, further refinement and expansion of the Disaster Management Information System, the development of a flood early warning system, the realignment of the disaster situational report system and the mounting of public awareness and education campaigns. In addition, disaster management workshops focusing on the NDMF (2005) and possible implementation strategies were held during 2005 in the nine provinces (Kilian, 2005).

Other work in progress at a national level includes setting up the Inter-Governmental Committee on Disaster Management and the National Disaster Management Advisory Forum, as stipulated in the Act. The establishing of an Emergency Operating Committee to deal with domestic and international disasters is yet another priority (Provincial Stakeholders' Disaster Management Working Session, King Williams Town, 2005).

Importantly, proposed national funding of research into recent severe flood events in 2006 in the Eastern and Western Cape signals a change in mindset at national level from previous emergency management approaches towards modern risk reduction approaches.

4.3.1 Eastern Cape developments

At a local Eastern Cape Provincial level, disaster management is coordinated by the provincial disaster management centre in Bisho, forming part of the Department of Housing, Local Government and Traditional Affairs. The province has been one of the more proactive provinces and one of the forerunners in taking up the lead in terms of implementing the requirements of the Act (Holloway, pers. comm., 2005). In fact, even prior to the promulgation of the Act, the province had already begun with risk reduction initiatives and programmes designed in accordance with those recommended in the earlier Green and White Papers. At present, the imperative for the province is to develop provincial and municipal disaster management plans and to conduct disaster risk assessments. For example, the Nkonkobe Local Municipality integrates its disaster management plan very effectively into the broad objectives of the IDP (Eastern Cape Socio-Economic Consultative Council, 2002). In addition, a number of municipalities have embarked on their own risk assessments, e.g. Amatole District Municipality, Buffalo City District Municipality and Nelson Mandela District Municipality. Risk assessments need to be conducted in stages from a broad provincial overview leading to more detailed local vulnerability assessments of at-risk communities (Reid, 2005).

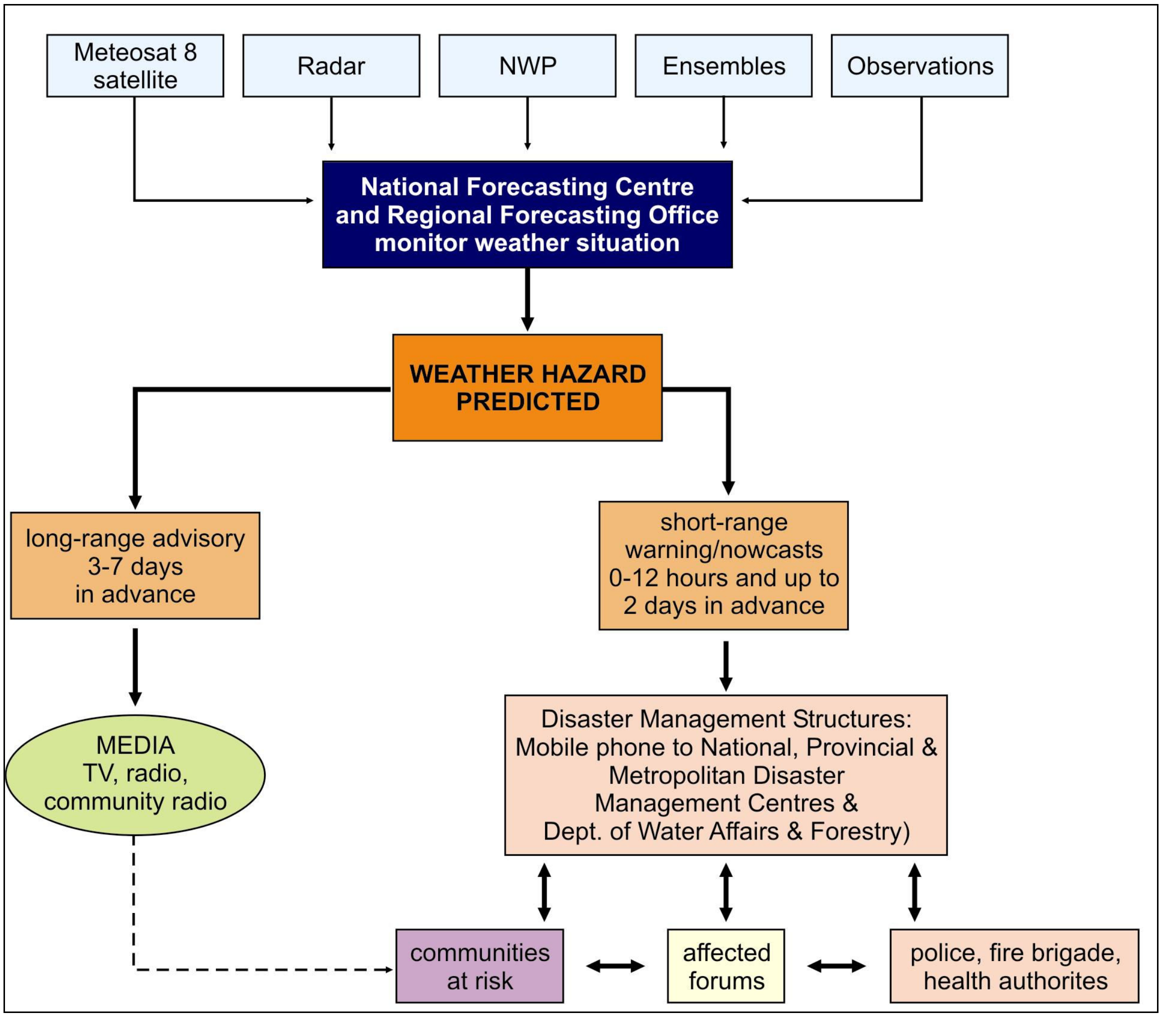
Cluster or project teams with consultants and specialists on board need to be established with the aim of investigating specific kinds of hazards experienced in the province, for example climate or weather-related hazards (Reid, 2005). In addition, a disaster risk management policy framework for the Eastern Cape is currently being drafted and is soon to be released for public comment (Reid, pers. comm., 2006).

In another significant development, the Eastern Cape was selected in 2005 to pilot a disaster management software support system developed by the Swedish Rescue Services Agency, provided free by the Swedish government (Kilian, 2005). To date, however, a satisfactory venue for running the system has not been decided (Reid, pers. comm., 2006).

The Eastern Cape has disaster management centres located in all metropolitan, district and local municipalities. They are staffed with personnel trained in risk reduction approaches and are generally well equipped. In addition, satellite offices are distributed amongst the local municipalities, but there is a pressing need for more offices and properly trained personnel in the remote north-eastern parts of the province (Williams, pers.comm., 2006). The centres located in the Port Elizabeth and East London urban areas have taken the lead in implementing proactive measures and use advanced technology to track and monitor disasters. For example, the Nelson Mandela Metropolitan Municipality, in conjunction with the South African Weather Service, has established a state-of-the-art GIS set-up and is currently busy with establishing a fine network of automatic rain gauges to cover the metropole. The intention is to integrate the rainfall data with an urban flood prediction model developed at the University of KwaZulu-Natal to provide better flood management information in the densely populated metropole (van Niekerk, pers. comm., 2006).

The province has also taken the lead in setting up a Provincial Disaster Management Advisory Forum, in accordance with the recommendations of the Act. This forum meets regularly and is represented by all major stakeholders in the province.

Figure 10 The end-to-end severe weather warning process of SAWS



Source: Poolman, 2006; 8

According to Reid (pers. comm., 2006) the most significant challenges facing disaster management in the Eastern Cape are building capacity in risk reduction, the integration of risk reduction into development planning (in particular IDPs) and the ongoing shift in mindset needed to realise the objective that disaster management needs to be integrated into all facets of provincial policy and planning.

4.3.2 The role of SAWS in provincial disaster risk management

SAWS plays a major role in disaster risk management in the province by providing a meteorological early warning service of potentially hazardous weather to all stakeholders.

This is a requirement of the South African Weather Service Act of 2001. In addition, close liaison is kept with the provincial disaster management centre in Bisho and the Nelson Mandela Metropolitan Municipality (NMMM) disaster centre (Poolman, 2006). Weather warnings and advisories are issued well in advance of impending severe weather via SMS, telephone, radio and television; in the event of severe storms, nowcasts with a short lead time of 0-6 hours are issued to warn communities of possible localised severe storm hazards. One of the major challenges facing SAWS and disaster management is the effective dissemination of early warnings to remote areas in the province (Poolman, 2006). It must be emphasised, too, that an effective early severe weather warning system is dependent on the efficient functioning of all the various components and stages of forecast and warning, from meteorological data collection through to the understanding and interpretation of warnings by hazard-prone communities (Wernly, 1994; Walter, 2005). It is crucially important to study how different communities understand early warnings and how this is translated into appropriate action (Tobin *et al,* 2005; Walter, 2005). The early warning monitoring and dissemination process used by SAWS, in conjunction with other role players is shown in Figure 10.

4.4 Summary

This chapter has shown how reactive disaster management approaches have been superseded by more proactive disaster risk approaches in many parts of the world. Within African countries there are encouraging signals that this shift is gaining momentum. Whilst there is evidence that the Eastern Cape is making progress towards implementing a risk reduction approach towards hazards and disasters, in accordance with the Disaster Management Act of 2002, there is still considerable work to be done to achieve all the legal requirements of the Act.

CHAPTER FIVE: ASSESSING HAZARD, VULNERABILITY AND RISK

> *The majority of disaster managers tend to believe that disaster risk assessment is synonymous with scientifically generated 'hazard mapping', and this is the sum total of the diagnostic process.*
>
> Wisner *et al.,* 2004; 333

5.1 Introduction

Using the stated aims and objectives of this study as the point of departure, this chapter aims to:

- critically evaluate theoretical models and approaches to conducting risk and vulnerability assessments found in the literature
- provide an overview of empirical research that has already been done in the field and to evaluate the applicability of the various theoretical models and empirical studies to this study
- outline the proposed risk assessment approach and methods to be used in this study

5.2 Definitions

The point has already been made in Chapter 2 that within the hazards community various definitions of hazard, vulnerability, risk and disaster, *etc*. abound in the literature, depending on the authors' epistemological orientations and subsequent methodological practices. Brauch (2005) and Brooks (2003) point out that there is no consensus within the natural hazard community on defining the concepts of hazard and risk. To complicate matters further, the various scientific disciplines outside of mainstream hazard science have developed their own interpretations of hazard and risk-related terminology, leading to what Thywissen (2006) has termed a 'Babylonian Confusion'.

In the light of this, it is crucial to define certain key terms and concepts to be used within the context of this study. After careful consideration, the following definitions have been chosen as appropriate to this study and will be referred to in this chapter. These have been taken from ISDR (2004, pp 16-17). Definitions of hazard, vulnerability, risk and disaster have already been provided in Chapter 2 (section 2.4).

Capacity: “A combination of all the strengths and resources available within a community, society or organisation that can reduce the level of risk, or the effects of a disaster.”

Coping capacity: “The means by which people or organisations use available resources and abilities to face adverse consequences that could lead to a disaster.”

Resilience/resilient: “The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.”

Hazard assessment: “The objective of a hazard assessment is to identify the probability of occurrence of a specific hazard, in a specific future time period, as well as its intensity and area of impact.”

Risk assessment/analysis: “A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods and the environment on which they depend. The process of conducting a risk assessment is based on a review of both technical features of hazards such as their location, intensity, frequency and probability, and also an analysis of the physical, social and economic dimensions of vulnerability, while taking particular account of the coping capacities pertinent to the risk scenarios.”

5.3 Theoretical models and approaches proposed in conducting hazard, vulnerability and risk assessments

Significant emphasis is placed on the importance of conducting comprehensive and methodologically sound risk assessments, as the first step in reviewing possible disaster reduction strategies (Wernly, 1994; RSA, 2002; ISDR, 2004; UNDP, 2004; Wisner *et al*., 2004; RSA, 2005).

UNDP (2004) encapsulates some of the pressing issues relating to the non-standardisation of approaches and methods used in conducting risk assessments: local and sub-national databases on risk assessments often do not use uniform data collection methods or frameworks for analysis; consequently a broad array of tools to measure vulnerability and hazard and methods for recording disaster losses have been developed. Such tools have been developed for the purpose of examining local hazard and risk contexts, bearing in mind local sensitivities. However, it is vitally important to formulate an assessment methodology which strikes a balance between the local context and the wider geographic environment (Tobin and Montz, 1997).

Available literature on the subject of risk assessment methods abounds. At the outset, it is important to differentiate between what may be termed a narrow "mechanical/technical" approach and a more encompassing "risk reduction/human vulnerability" approach. It is perhaps best to view the two as extremes at either end of a continuum of risk assessment approaches.

The narrow "mechanical/technical" approach is characterised by the use of methods relying on absolute measurement and quantification of hazard and risk. Von Kotze (1999a and 1999b) suggests that this approach has its roots in the technical expert knowledge system, where risk is simply seen as the probability of physical harm due to technological or natural processes. Risk in this view is simply computed mathematically by calculating the product of probability of occurrence and the magnitude of an event, expressed as risk = probability of occurrence x magnitude (Tobin and Montz, 1997). This can also be expressed as pure "climatological" risk or threat, where risk is modelled on an entirely statistical basis, for example Concannon *et al.* (2000) and Meyer *et al.* (2002). Outputs from such analyses are maps showing statistical probabilities of extremes occurring within certain geographic areas and within certain time frames. In addition, important human variables such as vulnerability, resilience and coping capacity are rarely incorporated into such an approach. The use of "expert knowledge" of the scientist in conducting the assessment, as opposed to involving communities in assessing perceived risks, is a common thread running through technical approaches to risk assessment (Brauch, 2005). Smith (1992) for example uses, Risk = P (probability of hazard occurrence) x L (expected loss). In its simplest form, risk may be seen as the product of probability of occurrence and the magnitude of an event (Tobin and Montz, 1997). The physical quantification of hazard dimensions such as frequency, duration, extent, *etc.* are measured and mapped and this is often expressed as 'risk', which is in fact incorrect and is a conflation of these two concepts (Tobin and Montz, 1997). The physical quantification of hazard should be seen as a necessary component of risk assessment, but not as the final result (Melching and Pilon, 1999; Wisner *et al.,* 2004).

Methods commonly used in such an approach include mathematical/statistical expressions of risk, such as mathematical probabilities, statistical simulations and modelling (e.g. Monte Carlo-type models, extreme value/event analysis, probability distributions functions, return periods, *etc.*) (Melching and Pilon, 1999; Smith, 1992; Bogardi and Kundzewicz, 2002). Whilst such objective, statistical assessments of risk do have a role to play, certain shortcomings have been noted. Smith (1992) warns that complex cause-effect relationships are always present in hazards and risks, and if statistically based models do not take all these complexities into account, invalid conclusions may be reached. Concannon *et al.* (2000) further add that a sufficiently large dataset is needed to allow any degree of confidence in statistical results. Substantial errors may result in extrapolating for long return periods where short-term datasets are used (Melching and Pilon, 1999).

At the other end of the spectrum of approaches to risk assessment is the "risk reduction/ human vulnerability" approach. This approach must be seen within the context of the paradigm shift referred to in Chapter 2, where disasters were no longer seen as purely natural events, but rather as the outcome of pressing developmental problems, resulting in a shift towards disaster *risk* reduction approaches. Tobin and Montz (1997; 298) encapsulate this changing view of risk assessment: "any analysis of risk must include vulnerability, including absolute and relative measures of the population and property at risk". Fundamental to this approach is the assessing of human/community indicators as part of the risk equation, such as vulnerability, coping capacity, resilience, *etc.* to gain a more comprehensive and in-depth perspective on risk. In this approach human factors cannot be divorced from the physical and risk is seen as a function of both potential hazard threat and human vulnerability. The most common expression of this is Risk = H (Hazard) x (V) Vulnerability (Wisner *et al*., 2004). Another way of expressing this is Risk = Probability of occurrence x Vulnerability, although the "probability of occurrence" is only one dimension of hazard and is rather restrictive (Tobin and Montz, 1997). Some authors have expanded the equation to incorporate resilience and coping capacity. For example, Mitchell (1990) theorises hazard as a multiple function of a number of elements, where Hazard = f (Risk x Exposure x Vulnerability x Response). In this view a clear distinction is made between vulnerability (the potential for loss) and exposure (the size, characteristics and assets of the at-risk population). To incorporate a multitude of asset-type characteristics into any study in South Africa would require intensive fieldwork as such detailed data are not always current or available. A complementary view is provided by Peduzzi *et al*. (2001) who view risk as resulting from three interrelated components, i.e. Risk = Hazard x Population x Vulnerability. In this view the characteristics of a population in a given area, combined with vulnerability (anticipated degree of loss) play a major role in defining risk. Expressed in another way, no risk occurs if there is no physical hazard present or nobody lives in the affected area, or if vulnerability is ameliorated by risk reduction measures (Brauch, 2005).

Vulnerability is the degree of susceptibility to a hazard; this incorporates physical, socio-economic and political factors that may exacerbate or ameliorate impacts to communities at risk (Lewis, 1999; Twigg, 2001). Cutter (1996) and Vincent (2004) emphasise that there is no consensus amongst authors on the exact meaning of vulnerability and how relative vulnerability is measured by using various indicators. It is crucial to bear in mind, too, that vulnerability is a relative measure; everyone is vulnerable to hazards to a lesser or greater degree (Downing, 2000). Importantly, vulnerability factors are essentially specific to an area and its community (Cutter, 1996; Lewis, 1999). One may, however, discern certain general or common socio-economic/political vulnerability indicators which have been found to be significant in studies of at-risk communities: population density, level of education and development, relative wealth/poverty, age-sex profile, health and sanitation, institutional and organisational mechanisms (including early warning capacity), community resilience and coping capacity (Twigg, 2001; UNDP, 2004; Vincent, 2004; Tobin *et al,* 2005).

It is suggested that the above indicators are pertinent to this particular study on severe storm risk in the Eastern Cape Province in South Africa, yet the lack of available or quantifiable data precluded certain institutional and coping capacity/community resilience indicators being included in the study (*vide* Chapter 6, section 6.2.3.2 and Chapter 8, section 8.2 for further discussion on and justification of the final indicators used).

Both quantitative and qualitative methods are used in the risk “reduction/human vulnerability” approach to gain a fuller picture of the extent of hazard and risk. However, measuring less tangible concepts and socio-economic variables such as resilience and coping capacity in exact numerical terms can prove to be difficult, yet this should not detract from the overall importance of including these in risk assessments (ISDR, 2004).

Methods and techniques commonly used in conducting risk assessment according to the “risk reduction/vulnerability” approach include integrated hazard and capacity and vulnerability analysis (Anderson and Woodrow, 1998), socio-economic and gender analysis, community risk assessments, community-based mapping techniques, risk perception studies, livelihoods analysis, *etc.* The assessment of risk is viewed as a collaborative process, involving all community members. A range of people-centred, participatory and action research methods can be employed, such as field investigations, focus groups, interviews, outreach programmes, *etc.* (Downing, 2000; ISDR, 2004; Wisner *et al*., 2004). In this regard, various kinds of matrixes and tick-boxes have been devised to aid in the assessment; for example the hazard, vulnerability and capacity assessment matrix is used at a local community level in the Philippines (Wisner e*t al*., 2004). Emergency Management Australia has devised a comprehensive check-list of all factors to be examined in risk assessments, in particular those factors affecting personal and community resilience (Wisner *et al*., 2004).

Various projects have been undertaken to derive risk indices for different countries of the world as an attempt to provide comprehensive global and regional assessments of disaster risk (Pelling, 2004). For example, the UNDP (2004) has derived a Disaster Risk Index (DRI) for 249 countries based on 24 socio-economic and environmental indicators in eight vulnerability categories for each country. Reliable and readily accessible global datasets were used in the calculation of a DRI for each country. The DRI enables the measurement and comparison of relative levels of exposure to hazard, vulnerability and risk between countries. In this study four hazard types (earthquake, tropical cyclone, flood and drought) were examined in relation to vulnerable populations. Importantly, risk was calculated for medium- and large-scale disasters only. Findings pointed to the importance of urbanisation and rural livelihoods in shaping disaster risk in various countries. In particular, it was found that rural poverty is one of the key factors which accentuates vulnerability and risk to hazards. (UNDP, 2004). Whilst the researcher acknowledges the value of such an approach that enables country and regional comparisons of risk to larger-scale disasters, there are severe constraints to accessing such accurate and specific technical information for the Eastern Cape. In addition, it must be pointed out that not all the indicators used in the DRI are appropriate to this study on severe storms. Similarly, recent studies have focused on deriving vulnerability indices and risk management indices at national and sub-national level in South America (Inter-American Development Bank [IADB], 2005).

Several authors advocate the use of “multi-hazard” models or an “all hazards” approach to examine multiple hazards which may occur in one place (Wernly, 1994; Tobin and Montz, 1997; ISDR, 2004; UNDP, 2004). The rationale behind using this approach is that single event types should not be considered in isolation but in combination. Tobin and Montz (1997; 303) point out that the multi-hazard approach is rarely used in assessing risk, even though many areas of the world are subject to multiple or compound hazards occurring at one place. Instead,

"the focus of research has been on the risk posed by single hazards, which does not provide a sufficiently comprehensive understanding of the overall risk that exists at a given place; it can lead to gross underestimates of risk and hazardousness and may result in inadequate risk management".

Given this, it is suggested that any study of severe thunderstorms, with the associated hazards of wind, hail, lightning and flash flooding, should be approached from perspective of the multi-hazards model.

Context-driven risk assessment is emphasised by authors, for example UNDP (2004) and Tobin and Montz (1997). The local vulnerability and risk factors should be assessed in detail to provide a better indication of how the multitude of socio-economic structures are interrelated at a particular place (Red Cross/Red Crescent Climate Centre, 2005). Each specific context will determine the overall approach and methods to be employed in the assessment. Von Kotze (1999a) calls for the inclusion of local knowledge in all risk assessments, making the point that local community knowledge is often more enlightening than expert knowledge and can play a very important role in unravelling the complexities of risk, the understanding and perceptions of which are deeply rooted in specific social systems. Linked to this view is the importance of the practice of "ground-truthing", i.e. assessing the actual situation *in situ*. Indications of community risk that are based primarily on expert knowledge systems need verification or "ground-truthing" in the field, where researchers may uncover very different picture of vulnerability and risk, based on local community perceptions. What may have been deemed a critical indicator of vulnerability in a local community, for example the type of housing, may in fact be of little concern in the view of the community, where something such as food security may be ranked as an even more pressing problem. Such intricacies of vulnerability and risk may only be uncovered by conducting research in the field, using a range of participatory methods listed above. Field research and community consultations not only increase the accuracy of risk assessment findings, but also provide critical insights into *pre-existing conditions of vulnerability and community perceptions of risk* (RSA, 2005) (author's emphasis). Smith (1992) and Lewis (1999) emphasise the distinction between risk assessments made by 'outsiders' and the perception of levels of risk by the actual people or communities involved, where there is often a disjuncture between the two. Research into community perceptions of risk posed by tropical cyclones in the Save Basin in Mozambique highlights this disjuncture (MacGregor, pers. comm., 2004).

Including historical data is seen as an important way of "benchmarking" current levels of hazard and risk (Wernly, 1994; Melching and Pilon, 1999; ISDR, 2004; World Meteorological Organisation, 2006). The process of compiling an historical database of hazard events should be done with great rigour and precision (Wernly, 1994). The ISDR (2004; 71) encapsulates the importance of compiling historical data and is worth quoting in full:

"…an historical analysis of disaster data provides the information to deduce levels of risk based on past experiences. In addition, historical disaster databases are essential to identify the dynamic aspects involved in vulnerability, providing the criteria to assign relative weights to different dimensions of vulnerability in risk assessment exercises".

Conducting historical research is an important step in understanding the extent of hazard, vulnerability and disaster loss, locally, nationally and globally (UNDP, 2004).

The value of conducting historical data analysis is underscored in the South African Disaster Management Act (2002), and in the subsequent National Disaster Management Framework (2005). With reference to examining "potential windstorm or tornado risk in a rural area" (RSA, 2005; 32), methods suggested include conducting a history of past events, an historical climatology and seasonal analysis, and consultations with local leadership. Expertise needed to conduct a risk assessment from this perspective includes indigenous knowledge, community facilitators and climate scientists. The NDMF (2005) particularly stresses the importance of conducting an audit of past significant events and “disaster” events. It is of the utmost importance to include both frequently occurring small and medium-size events and infrequent large-scale disasters in an historical review, as this can be extremely valuable in building up a comprehensive inventory of impacts at a variety of scales. Alexander (1999) comments that recurrent smaller-scale hazards tend to be more damaging in the long term than less frequent large-scale impacts. As a first step, this can help to identify areas and communities who are most at risk on a broad regional basis, which can then focus on more detailed, in-depth assessments of local areas and the affected communities on a smaller scale (NDMF, 2005). Local nuances and sensitivities need to be investigated at a community level to uncover variations in the general pattern of risk which a regional or macro overview will initially provide. Important sources of information on both small-scale and large-scale impacts include local and regional newspapers, community members and traditional leaders, emergency and disaster management services and specialist research reports. Newspaper articles provide a valuable source of information but may provide a limited insight into highly recurrent small-scale events that are often not recorded in major newspapers (UNDP, 2004). Therefore, it is particularly important to consult as many sources of information as possible, especially where record-keeping is known to be weak and where there is a lack of data (Melching and Pilon, 1999). In addition, knowledge of how the data were collected is crucial to the record-gathering process (Concannon *et al*., 2000).

Conducting historical research into past events is difficult in a number of respects. Firstly, the process is very intensive and time-consuming if done rigorously. Reports of past events are not easily sourced in areas where record-keeping has been erratic and sparse. This is particularly the case in under-developed regions, where record-keeping has not been seen as a priority and where institutional structures responsible for accurate record-keeping are lacking. The researcher has found this particularly problematic in the Eastern Cape, where the more remote rural areas of the former self-governing territories of the Transkei and Ciskei have suffered from a lack of consistent and methodical reporting over the years, particularly during the Apartheid rule. Reporting has, however, improved measurably in these areas since the African National Congress (ANC) has come into power and the importance and profile of disaster management improved in the province.

Secondly, no historical inventory of past events can ever be complete or totally reliable. Large-scale damaging events will be reported, yet the medium to small-scale events are more likely to go by unnoticed or unreported, even in developed, densely populated areas. This difficulty though does not mean that no attempt should be made in constructing a database of events, however sparse the reports may have been in the past - some indication of the pattern of past occurrences is better than none at all (Tyrrell, 2001). Perhaps it is best to approach any historical event study from the perspective of working with the *best available data one can reasonably find*, and not the data one would like to have. Thirdly, the lack of standardised reporting in the past can hamper research quite considerably. Report formats vary in length, detail and content (scientific or descriptive, exaggerated or brief, *etc.*), which makes comparisons with other events very difficult. This is particularly the case in attempting to deduce the severity of impact of past events based on reports which are predominantly descriptive in nature. The difficulty lies in trying to sift out some factual evidence from overtly subjective reports. Lastly, reliable statistical assessment of risk is likely to be constrained by a less than reliable historical database (Smith, 1992; Concannon *et al*., 2000). The danger in this case is to conduct an assessment which is too subjective and has very little factual, quantifiable data.

The NDMF (2005) also stresses that vulnerability (socio-economic, political and environmental) should also be assessed as a critical component of the risk assessment process and importantly should be done concurrently with the more technical hazard assessment.

5.4 The use of GIS as a tool in conducting risk assessments

The point was made in Chapter 3 that the rapid development of technology in scientific research, particularly remote sensing, spatial modelling and GIS (Geographical Information Systems), has made its mark in the hazards research field too (Wadge *et al*., 1993). Tobin and Montz (2004; 567) provide a sane perspective on the use of technology in assessing hazard and risk, suggesting that “the latest technology should be used for illumination and not to support pre-constructed ideas”. In this regard, it is perhaps best to see GIS as only one of a suite of tools available to researchers in the risk assessment process and not as an end in itself. GIS must not replace the work of the properly trained and informed hazard scientist (Tobin and Montz, 1997; 2004).

In hazard and risk analysis, GIS is used to induce levels of risk by integrating layers of information, both physical and socio-economic. The point has been made by various authors that GIS is particularly valuable where there are multiple factors at play, as is the case in multi-hazard analysis (ISDR, 2004; Tobin and Montz, 1997). Conventional mapping techniques, e.g. hand drawn maps, may not reveal the complexity of inter-relationships at work in areas especially where multiple hazards are present.

The use of GIS is not without its problems, however. Firstly, researchers may become so reliant on the impressive array of information and capabilities that GIS has to offer that they may lose sight of the real situation "on the ground". In theory, it is quite possible to complete a hazard assessment without ever having been in the field to ground-truth the data or findings. Quick and easy hazard maps showing risk zones and risk contours which are compiled by sophisticated GIS packages and computer models are very easily generated by technical people who may not necessarily be hazard or risk specialists, and may lack the requisite theoretical underpinnings (Carrara *et al*., 1999). In practice, though, such a narrow and technical approach, using data that are mainly derived from secondary sources, would be inaccurate and unreliable. In fact, the point has been made that in its extreme form, GIS may serve to widen the breach between limited information provided by technical risk assessments and the levels of risk perceived by communities (ISDR, 2004). Secondly, the inclusion of socio-economic variables into GIS models is problematic, given the wide array of measuring techniques and instruments used to quantify socio-economic vulnerability (ISDR, 2004). There has been some effort in this area, however, as evidenced in a study commenced recently using GIS to map social vulnerability to tsunami impacts in India (*Natural Hazards Observer*, 2005). Thirdly, there are many under-developed areas of the world where GIS technology is not available and this may restrict its use in such places.

In South Africa, various government departments and research councils have used GIS technology in more technical hazard mapping, as opposed to vulnerability and risk mapping, e.g. the Agricultural Research Council, the Department of Water Affairs and Forestry and the Department of Health (ISDR, 2004).

Recent attempts to produce scientifically generated hazard and risk maps by environmental consulting organisations in South Africa require discussion. The requirements of the Disaster Management Act (2002) have spawned a number of studies which have been commissioned by provincial and municipal authorities. Unfortunately, in the researcher's opinion, the assessments that have been completed have been compromised by financial and time imperatives, which has necessitated a 'quick and easy' approach. A case in point is the hazard and risk assessment completed recently for the Nelson Mandela Metropolitan Municipality and Ekurhuleni Metropolitan Municipality (Alberton area in Gauteng) (Strydom and Braune, 2005).

In the words of Strydom and Braune (2005; 3):

"A compromise has to be found between obtaining long-term spatially represented and representative data from historical records vs. achieving reasonably inexpensive data generation for immediate risk assessment needs that would aim at addressing the requirements of the Act and the National Disaster Management Framework … it can be done more quickly than would be done through sifting through years of records and attempting to capture in absolute accuracy the details of the hazards and vulnerabilities that communities face".

A major criticism to be levelled against this approach is the admission made by the authors that there is very little value in conducting sound historical research into past events. Without an indication of the historical chronology of events and with no subsequent baseline data, the final hazard assessment will be compromised and inaccurate.

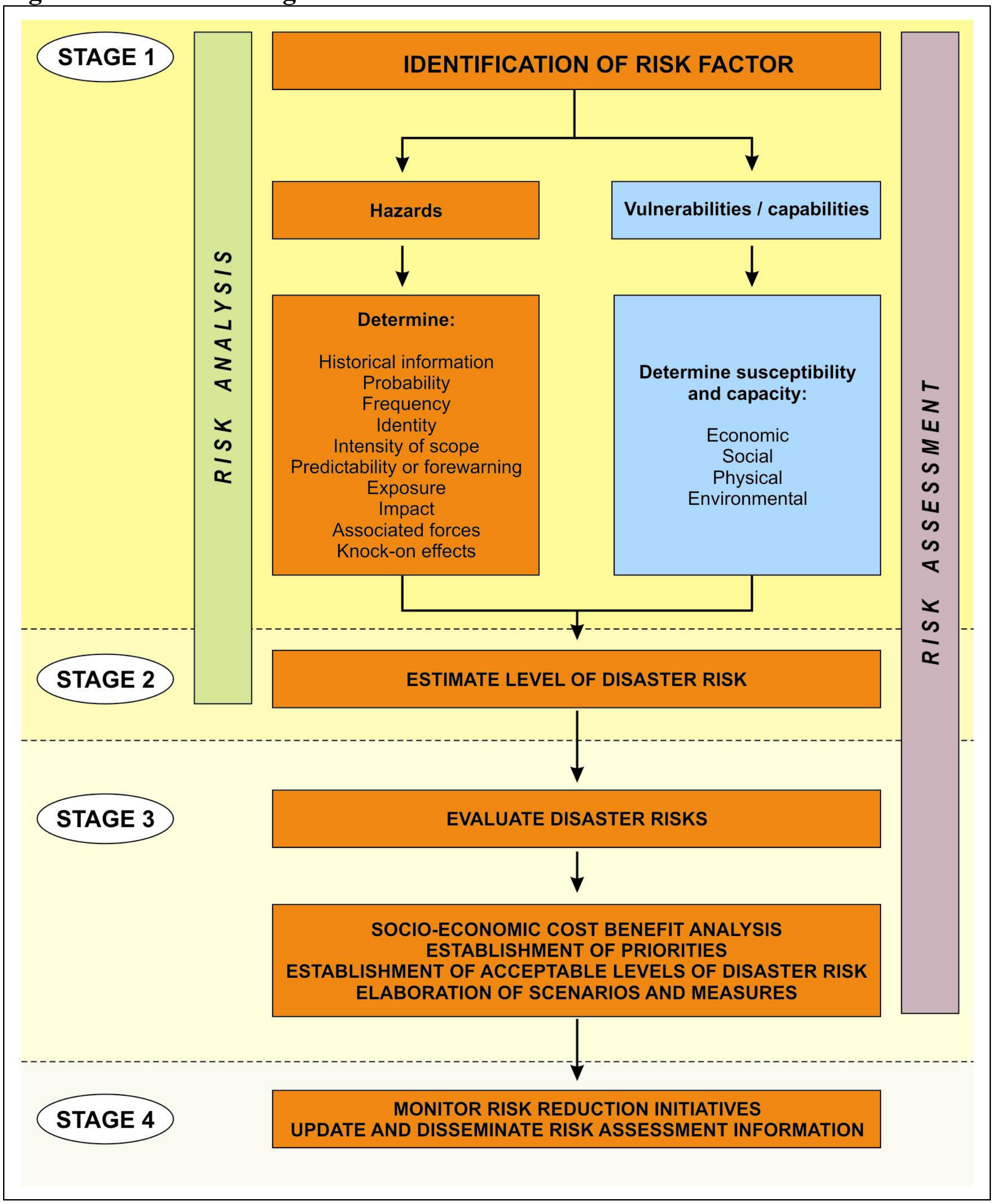
5.5 Stages in conducting hazard and risk assessments

Melching and Pilon (1999) urge that the assessment of vulnerability should not be undertaken as a second next step but should be done at the same time as the assessment of hazard. In theory this is desirable, as examining the two processes in tandem may reveal crucial aspects of risk which may not have been discovered had they been done as consecutive steps. A number of risk assessment models that have been proposed, for example ISDR (2004) and Wernly (1994), start with the identification and assessment of hazard (frequency, duration, impact, *etc.*) and subsequently proceed to the assessment of vulnerability (physical, social, economic and environmental). Brauch (2005), however, suggests that this is not always the case and some assessment approaches propose that the assessment and ranking of vulnerability should serve as the starting point. Risk is dynamic and Tobin and Montz (1997) and Wisner *et al*. (2004) make the important point that risk assessment should not be seen as a once-off exercise, but should rather be viewed as a continuous process and should be conducted before, during and after impacts. The researcher contests that perhaps beginning with the hazard assessment is a logical starting point, but recognises that it is desirable to have a broad indication of vulnerability factors before commencing the analysis of hazard as this will provide valuable insights into the process. Investigatory fieldwork in known high frequency areas prior to conducting the final risk assessment may prove to be a necessary step in the process. In-depth vulnerability assessments conducted at the local or community level may be done later to interrogate the broad pattern of risk in more detail (NDMF, 2005).

The NDMF (2005) provides a clear scheme outlining the various stages to be used in assessing disaster risk, shown in Figure 11. This is based primarily on the risk framework suggested in ISDR (2004), but is more explicit and detailed.

This framework was designed specifically for examining disaster risk, but in the view of the researcher it can be used to examine hazard threats at a variety of scales, from small local occurrences to infrequent, high impact events. The problems associated with defining ‘disaster’ have been mentioned in Chapter 2; it is best not to concentrate on only narrowly-defined disasters, but also to include the full scale of threats and impacts in conducting assessments. With reference to Figure 11, the following stages have been summarised from the NDMF (2005, pp 28-30).

Figure 11 The basic stages of a disaster risk assessment



Source: NDMF, 2005; 29

Stage 1 is the initial stage and this involves *identifying and describing the specific risk(s)* to be assessed.

1. Identify and describe the hazard(s) with regard to frequency, magnitude, speed of onset, affected area and duration, *etc.*
2. Describe and quantify vulnerability, e.g. infrastructure (including homes and dwellings), services, economic activities and natural resources exposed to the hazard.
3. Estimate the probable losses resulting from hazard impacts on those who are vulnerable.
4. Identify relevant capacities, methods and resources presently available to manage the risk. In addition, assess the effectiveness of these as well as any possible inefficiencies in government departments, *etc.*

Stage 2 is concerned with *analysing the risk(s)*.

1. Estimating the level of risk associated with each hazard to determine whether the resulting risk is a priority or not. Match the likelihood of a hazard with its anticipated impact and subsequent consequences.

Stage 3 is concerned with *evaluating the risk(s).*

1. Prioritising the threats from multiple hazards. Priority at-risk populations, communities, households, *etc.* are identified at this stage to be the focus of "highly specialised, multidisciplinary, comprehensive risk assessments". These assessments must inform planning and implementation of integrated risk reduction initiatives.

Stage 4 is the final stage and is concerned with *ongoing monitoring* of risk reduction initiatives, changing risk profiles and patterns, and the updating and disseminating of information.

The framework provided by the NDMF (2005) is both comprehensive and based soundly on 'international best practice', examples of which are to be found in ISDR (2004). As such, and in accordance with the stated aims, scope and conceptual framework (Figure 2, Chapter 1) of this particular study, the NDMF framework will be adopted for use in conducting the assessment of severe storm hazard and risk in the Eastern Cape. Importantly, only stages 1 to 2 of the framework will be used for the study, *viz*. the identification and description of risk, and the analysis of risk (estimating levels of risk for various geographic populations). In addition, whilst a major focus will be on hazard identification and description, the study will also investigate broad patterns of vulnerability in order to deduce general patterns of risk. Whilst the study recognises a range of contributory risk factors, the assessment of capacity, coping capacity and resilience is not the focus of the study. Cutter (1996) and the IADB (2005) make the valid point that often detailed vulnerability, capacity and risk assessments are best conducted at a micro or local level; conducting broad, regional or macro assessments may mean sacrificing important detail at the local community level. The importance of ground-truthing in this context has been emphasised already in this chapter. The researcher intends this study to provide a macro view of hazard and risk for the Eastern Cape province as a whole, in order to identify geographic populations and areas which are most at risk so that further research may be conducted in these hazard and risk "hot-spots" at a more detailed, local level.

5.6 Summary

This chapter has shown that there is a broad range of hazard and risk assessment approaches and methods available in the literature, ranging from the more technical hazard assessments to those which place more emphasis on risk reduction. Tobin and Montz (1997) stress three elusive aspects of risk: it is dynamic, it is a moving target, and it confounds. Whilst this *caveat* must be borne in mind, a major objective of this study is to develop an appropriate assessment framework that will reveal accurate geographic patterns of storm risk, which in turn will assist various stakeholders in reducing risk in the province; the researcher asserts that the NDMF framework outlined above is the best suited for this purpose.

CHAPTER SIX: RESEARCH METHODS AND PROCEDURES

> *It is clear that the absence of references to tornadoes and other whirlwinds in the historical record does not mean that they did not occur. Even today, it appears that only a small proportion of events are reported in a way that will preserve their record. But the resulting difficulty of the task does not make the need for constructing a reliable historical database any the less significant.*
>
> Tyrrell, 2001; 287

6.1 Introduction

The previous chapters provide the theoretical and contextual background to the methodology adopted in this study. The main points from these chapters that have informed this study and which have guided the research methods and procedures discussed in this chapter are summarised below:

- A "multi-hazards" conceptual framework, which includes both physical and human parameters of severe storm risk, allows for a deeper and more comprehensive analysis of the particular situation in the Eastern Cape. Accordingly, the conceptual framework adopted for this study (Figure 2 in Chapter 1) emphasises the following:
  - risk is the product of both hazard and vulnerability
  - risk is often compounded by the multi-hazard nature of severe storms
  - higher risk is associated with greater impact and losses
  - risk has a geographic context (located in time and space) and is dynamic

- Research shows that the socio-economic impact of storms on different communities varies greatly in the Eastern Cape. In this respect the rural/urban disparity is particularly significant; disadvantaged communities living in the remote rural areas suffer much greater absolute losses. Whilst most of the previous research in this country has dealt with the physical/climatological features of severe storms, little has concentrated on the crucial aspect of socio-economic impact. Therefore, a thunderstorm severity (TS) scale based on recorded impact was specifically developed as a tool for analysing the differential storm impact patterns in the Eastern Cape (section 6.2.2.7 of this chapter).

- The reporting and record-keeping of severe weather events (particularly the more localised, smaller-impact events) has been sporadic and unreliable in the past in South Africa, and particularly so in the Eastern Cape. Accordingly, every effort needs to be made to conduct exhaustive historical research into past events and, where possible, to consult a wide range of available sources to validate and verify reports. Building historical inventories requires considerable time and effort, yet should be done meticulously in order to establish as accurate a baseline of events as possible (Tyrrell, 2001).

- The process of ground-truthing, i.e. conducting field research and interviews *in situ* in high storm risk areas is very important in respect of:
  - Verifying the accuracy of storm reports obtained from secondary sources
  - Confirming the researcher's assumptions regarding the vulnerability of communities. Vulnerability factors are often hazard-specific and therefore need to be selected with this in mind. Further explanation on the ground-truthing procedures followed is provided in the following sections.

- GIS must be viewed as valuable tool to assist in the analysis of storm hazard and risk and not as an end in itself. In this respect, the expertise, intuition and critical-thinking abilities of the researcher should always remain at the forefront of any technical hazard/risk mapping exercise.

- Research efforts in the hazards and risk field need to be empirical and applied in order to provide outcomes and recommendations that can be used by professionals in the field of disaster risk mitigation. This is particularly needed in the Eastern Cape, where critical information on risk-prone communities and areas is required by municipal and provincial disaster management authorities to guide their operational responses. It is suggested that the information provided in this thesis and, in particular, the storm vulnerability map (Figure 52, Chapter 8) and risk map (Figure 54, Chapter 9) of the province will play a significant role in assisting these authorities to implement a proactive, risk-reduction approach to disaster management.

This chapter sets out the methods used to obtain, process, categorise and analyse the storm data in light of the aforementioned points.

The purpose of the storm categorisation is to prepare the raw storm data into a more usable format that will aid in analysing the spatial and temporal trends of storm hazard and risk for the province.

6.2 Steps involved in obtaining, processing and categorising the data

6.2.1 Obtaining historical records of severe storm events in the Eastern Cape

This section lists and describes in detail the data sources used to obtain reports of severe storm events in the Eastern Cape. Numerous sources were consulted in order to develop as comprehensive and accurate an inventory of storms as possible.

6.2.1.1 Main data sources

- CAELUM, 1991: *A History of Notable Weather Events in South Africa: 1500-1990,* South African Weather Service, Pretoria
- CAELUM, 1998: *Notable Weather and Weather-Related Events in South Africa:* 1991-1998, South African Weather Service, Pretoria
- CAELUM , electronic version, 2004a: *Notable Weather and Weather-Related Events in South Africa:* 1961-2004, geocoded, South African Weather Service, Pretoria
- Newspaper and magazine reports:
  - Regional newspapers with large circulation: *The EP Herald* (Port Elizabeth)*, Die Burger* (Port Elizabeth), *The Daily Dispatch* (East London)*, The Weekend Post* (Eastern Cape)
  - National newspapers: *The Citizen, Independent Online*
  - Local newspaper: *Grocott's Mail* (Grahamstown/Albany area)
  - National magazine: *The Farmer's Weekly*

- SABC TV News Reports (online)
- Official municipal, district and provincial disaster management reports for the Eastern Cape
- E-mail reports of storms from Mr G Sampson (SAWS, Port Elizabeth), Mr H van Niekerk (SAWS, Port Elizabeth) and Mr K Rae (SAWS, Pretoria)
- E-mail reports of storms from Mr M Williams of OR Tambo District Disaster Management and Mrs N Hansen of Amatole District Disaster Management
- South African National Disaster Management Centre (Pretoria) (online), Eastern Cape Disaster Incidents
- Personal interviews with the following key persons:
  - Mr B Adonis (Headmaster, Laer Blinkwater, Fort Beaufort)
  - Mr L Roberts (owner of "Argyle Farm", Fort Beaufort)
  - Mr C Painter (owner of the farm "Riverside", Fort Beaufort)
  - Mr J Paton (Manager, Hobbiton-on-Hogsback Education Centre)
  - Mr M Williams (Assistant Director: Disaster and Fire Section, OR Tambo District Municipality, Umtata)
  - Mr M Mpiti (Senior Disaster Management Officer, OR Tambo District Municipality, Umtata)
  - Mr M Arnold (owner of the farm "Grandon", Bathurst)
  - Dr R Morris (former resident missionary at Mount Ayliff)
- Telephonic interview with Mr J W Nel (owner of the farm "De Hoogte", Somerset East)

The three CAELUM publications published by the South African Weather Service listed above provided a valuable source of information for historical storm events in the Eastern Cape. Newspaper reports and articles collected by the SAWS library over many years provided the main source of information in the CAELUM publications, supplemented by information from meteorological report forms, monthly reports, annual reports and newsletters (SAWS, 1991). The following report of a severe hailstorm at Cradock on 29 March 1989 published in CAELUM (2001; 118) provides an indication of the type of report which the researcher analysed to gather information for the database: "A vicious hailstorm caused nearly R300 000 worth of damage on a farm 'Dosaka' in the Visrivier district near to Cradock. Irregularly shaped hailstones, as large as tennis balls, killed 200 Angora goats. This was one part of a storm which moved across a wide area causing hundreds of thousands of Rands worth of damage to vehicles, houses, gardens and crops in the districts of Middelburg, Visrivier, Cradock, Hofmeyr and Molteno".

A limitation that must be noted in respect of the CAELUM publications is the emphasis on selecting articles from newspapers published the major urban centres in South Africa – this results in a heavy bias towards events that have occurred in the larger urban areas. To compensate for this bias the researcher consulted a range of other sources listed above in order to gain a broader coverage of storms for the whole of the Eastern Cape and not only the main urban centres. Regional and local newspapers in the Eastern Cape were searched electronically for archived storm reports. Earlier editions of newspapers, for which electronic reports were not available, were searched manually at the municipal library in Port Elizabeth, with the assistance of the senior librarian.

Monthly incident reports obtained from the provincial disaster management centre in Bisho in the Eastern Cape provided a wealth of information on storms events, particularly over the last ten years. In addition, reports obtained from municipal and district disaster management offices in the province provided very important supplementary information on more localised events.

More recent storm reports were also obtained from SAWS climatologists in Port Elizabeth and Pretoria. These reports were extremely valuable as they proved to be very accurate and reliable.

The National Disaster Management Centre in Pretoria has compiled an electronic database of all severe weather events in South Africa since approximately 1999. The information in the database was provided by all provincial disaster management centres. This provided a valuable supplementary source of storm events, although the electronic database for the Eastern Cape has not been maintained and updated since 2003.

Ground-truthing and personal interviews

Ground-truthing in the form of field research and personal interviews was conducted with stakeholders and affected persons in high storm risk areas in order to:

- validate/confirm the details of storm reports obtained in the secondary sources
- gain a better personal insight into the socio-economic impact of storms
- investigate assumptions regarding vulnerability and coping/mitigation measures at a local level.

Two main high-risk areas in the province were selected for field research and interviews with local inhabitants, *viz.* the Fort Beaufort/Alice/Hogsback area and the Umtata area – these will be discussed below.

It has been shown in previous chapters that the Fort Beaufort/Alice/Hogsback area has experienced a number of severe storms over the past ten years, in particular hailstorms and tornadoes. Accordingly, the researcher made a number of visits to the area during the six-year period of research. Semi-structured and informal interviews were held with a broad range of people who has personally experienced severe storms (commercial farmers, villagers, a school headmaster and an education centre manager, details listed above) in order to gain a more accurate and comprehensive understanding of the above-mentioned aspects. Interviewees were carefully selected to represent an accurate social and geographic cross-section of inhabitants in the area, according to ethnic group, occupation, education, age, gender and relative wealth. Questions and discussions with interviewees focused on:

- verifying the details of previous storm impacts in the area
- determining the prevailing demographic, socio-economic and physical living conditions of individuals and communities that provided a better indication of vulnerability to storm impacts and possible coping mechanisms
- gauging access to and understanding of early warnings from the SAWS and disaster management

- exploring scientific and indigenous knowledge of severe storms

Information gleaned from the above questions and discussions are referred to in the ensuing Chapters 7 to 9.

The high-risk Umtata region was visited in July 2006 by the researcher at the invitation of disaster management officials of the OR Tambo District Municipality. Local disaster management officials coordinated field trips to a number of rural villages in the Umtata area which had been affected by severe storms (particularly tornadoes, lightning and damaging winds) in the past. The researcher interviewed a number of residents from a cross-section of affected villages in the Umtata area in order to gain a better insight into rural vulnerability, which was crucial in deciding on the final 11 vulnerability indicators discussed in section 6.2.3.2 of this chapter. A particularly informative visit was made to Sitebe Village, located approximately 45 km to the south-west of Umtata, which had experienced a tornado in January 2006. Site investigations and discussions with local residents confirmed that, although the impact of the storm had been particularly severe, with loss of life and injury, very little external assistance had been received to help the very poor community rebuild houses and infrastructure. Most of damaged structures in the village were in precisely the same state they were after the storm that had occurred six months previously. Similarly, seven months after the devastating tornado occurred in the Mount Ayliff area in 1999, government officials were still undecided on how to distribute relief to affected villages (Morris, pers. comm., 2006). This provides confirmation of how extreme poverty and poor service delivery by local and district government can heighten the vulnerability of rural communities. Furthermore, interviews with disaster management officials in Umtata highlighted the problem of under-reporting of storm events in the area and the difficulties in reaching remote communities after storms had occurred.

Interviews were conducted with inhabitants from two further storm-affected areas, *viz.* Bathurst, where an unusually severe hailstorm had devastated a commercial pineapple crop in April 2005, and Mount Ayliff, a high risk area in the extreme north-eastern part of the province. The farmer who had experienced the worst losses in the hailstorm was selected for interviewing, whilst an interview with a former American missionary who had worked in the Mount Ayliff area from 1991 to 2002 provided valuable insights into storm risk in a highly vulnerable and impoverished rural area of the province. In both cases semi-structured and informal interviews were conducted. As for the other areas discussed above, questions concentrated on verifying the details of previous storm events and on exploring the demographic, socio-economic and physical living conditions in the area.

6.2.1.2 Additional data sources (used mainly for confirmation and verification)

- Laing, M., 1999: *A list of most recent tornadoes in S.A.: 1999-1989,* South African Weather Service, Pretoria
- Goliger, A.M., Milford, R.V., Adam, B.F. and Edwards, M., 1997: *Inkanyamba: Tornadoes in South Africa,* Division of Building Technology, CSIR and SA Weather Bureau, Pretoria.
- D'Abreton, P., 1991: A synoptic characterisation of some South African tornadoes, *South African Journal of Science,* 87 (January/February), 56-61.
- Perry, A., 1995: Severe hailstorm at Grahamstown in relation to convective weather hazards in South Africa, *Weather,* 50 (6), 211-214
- Roberts, G. and Sampson, G., 1996: *Tornadoes wreak havoc in Fort Beaufort district*, South African Weather Bureau Newsletter, January 1996, Pretoria.
- Van Niekerk, H. and Sampson, G., 1999: *Hell Season or par for the Course: Tornadoes over the Eastern Cape 1998/99 Season*, Internal Report Number OB/17, South African Weather Bureau, Pretoria.

6.2.2 Entering storm events and their characteristics into an Excel database to be used as the basis for further analysis

The following steps were involved in this process:

- Selecting severe convective storm events from the records/data screening
- Deciding/verifying the actual date of occurrence
- Locating the exact place of occurrence
- Describing storm event types

- Selecting comments for entering in the database
- Classifying the general comments into discrete indicator categories
- Deriving a storm severity scale based on observed/recorded impact
- Ranking hail storm intensity based on the CSIR hail intensity scale
- Analysing the storm data in a GIS (Arc View 9.1)

The following section provides a detailed explanation of these steps.

6.2.2.1 Selecting severe convective storm events from the records/data screening

Sources listed above were carefully searched for all references to and reports on severe convective storms in the Eastern Cape Province and in the southern KwaZulu-Natal areas around Kokstad and Matatiele. Reliable reports were found dating back to 1897 in CAELUM (1991); accordingly, it was decided that this would be the starting date of the record. Records in CAELUM (1991) and Goliger *et al.* (1997) proved most reliable for the earlier historical record; more recent events have been better documented in the main Eastern Cape newspapers and disaster management reports and these proved particularly useful for providing more detailed information on events during the last 10 to 15 years. Wherever possible, multiple sources were consulted to substantiate and verify incidents. Storm events were selected for inclusion in the database from all sources if they conformed to the following working definition of a severe convective storm, *viz.*

An intense, localised, short-duration thunderstorm accompanied by damaging winds (including tornadoes), hail, lightning or flash flooding.

The point has been made in Chapter 3 that past research in this country has focused on larger scale "disaster" events, such as tornadoes and storm events caused by other weather phenomena. In spite of the serious risk posed by frequently recurring, localised severe convective storms in the Eastern Cape, previous research has neglected this area. Accordingly, it was decided to focus on only severe convective storms and not to include other storm or severe weather types. Two important criteria were used to discriminate between severe convective storms and other types of severe storms. Firstly, thunderstorms arising from synoptic scale or mesoscale situations of longer duration, such as cut-off lows or 'black south-easter' conditions, which can spawn widespread (regional) embedded thunderstorms, were not included in the database. Severe winter storms associated with the passage of mid-latitude cyclones were also excluded. Secondly, the season of occurrence was used as an important discriminator in cases that were otherwise difficult to classify due to lack of information; in these cases summer events were included while winter events were excluded, given the fact that the vast majority of severe convective storms develop in the warm summer months. It is conceded that there are exceptions to this and that some of the most severe storms have occurred in South Africa outside of the normal summer period. Two notable examples of this are the Cape Flats/Manenberg tornado in the Western Cape, which occurred in August of 1999 and the Maclear/Ugie tornado in the Eastern Cape, which occurred in June of 1994. Both resulted in disaster areas being declared and accounted for considerable damage, yet were anomalous in respect of their mid-winter occurrence. There was, however, little doubt that both events were severe local convective storms due to convincing climatological evidence and the impact patterns evident on the ground (van Niekerk, pers. comm., 2006; Goliger and de Coning, 1999). The Maclear/Ugie event in the Eastern Cape was therefore included in the study.

Storm reports in all sources that did not satisfy the conditions of the working definition were excluded. It is likely, however, that some storms were excluded in the process of selection due to the incomplete, scanty nature of many of the reports. It was decided to err rather on the side of caution, adopting a conservative approach that excluded doubtful cases. It is important to note, too, that many reports did not satisfy all the criteria of a severe convective storm, yet the overall evidence justified their inclusion in the database. A total of 179 storms was selected; these were entered into an Excel database for further analysis.

6.2.2.2 Deciding/verifying the actual date of occurrence

In some cases conflicting dates of the same event were found in different sources. In all cases, however, the difference was no more than a day or two; both dates of possible occurrence were recorded in the database. The researcher believes that while the actual day of occurrence does provide some useful information, what is more important is the month and year of each event for analysing seasonality and inter-annual patterns. Only two events provided no indication of the day on which they occurred.

6.2.2.3 Locating the exact place of occurrence

Reports varied greatly in respect of reporting the place of occurrence of storms. In most cases specific cities, towns and villages were given as the place of occurrence. In other cases different sources for the same event pointed to separate locations; in such cases all locations were included in the database, provided that the locations were geographically proximate, e.g. Flagstaff/Lusikisiki#; Mount Ayliff/Tabankulu# , signified by the symbol #. The co-ordinates were provided for the first place mentioned in the database. Another problem arose with respect to the location of events in very small rural villages and farms, which are remote and not well known. In such cases the closest larger settlement was provided for reference, e.g. Willowvale (Nthlonyana Village). Similarly, some villages shared the same name, e.g. Tsolo, which is found both near Umtata and King William's Town. In such cases other information in the reports provided clues as to the correct location. The corruption of the spelling of indigenous Xhosa place names proved problematic in certain cases. A case in point is indigenous place name "Kentani", which has been corrupted to the English "Centane". Reports referred to the latter and this was not listed in the two databases of place names that were used to locate places, *viz.* the *SA Explorer* (2005) database of place names in South Africa and the National Geospatial-Intelligence Agency / GEOnet Names Server (GEOnet Names Server, 2006) database of foreign place names. This was overcome by consulting 1:50 000 and 1:250 000 maps of the wider area where the indigenous place name "Kentani" was located and the co-ordinates were calculated manually.

A number of reports made reference to several villages affected in a broad area and in such cases the closest central town was chosen as the location, e.g. villages affected around Lady Frere would be entered as Lady Frere* in the database, with the asterisk signifying that a number of surrounding villages were affected.

6.2.2.4 Describing storm event types

Storms were described according to the following event types, based on the information provided in the reports: tornado, wind, hail, lightning, flash flood or a general severe storm. Where reports specifically mentioned any of the five hazards, such descriptions were included for each storm in the database, e.g. tornado and hail; hail, wind and flash flood, *etc.* In cases where no specific mention was made of any hazard, the description of general severe storm was used.

Classification of tornadoes, as distinct from other storm types, proved problematic; where there was no definite evidence of tornado damage then the more general severe storm or wind classification was used. Tornadoes previously classified according to the Fujita-Pearson scale (F0-F5) by Goliger *et al*. (1997) and van Niekerk and Sampson (1999) were left as such as the researcher is of the opinion that these events were thoroughly investigated and subsequently classified as accurately as possible, while remaining aware of the inherent shortcomings of the Fujita-Pearson scale (section 3.6.1). One of the more recent storm events, the Umtata (Sitebe village) case on 12 January 2006, has been tentatively identified as a tornado by the SAWS, yet its exact Fujita-Pearson scale classification remains undecided to date (van Niekerk, pers. comm., 2006). The researcher believes that while it may be of interest to investigate the physical characteristics and climatology of tornadic storm events in more detail, this is not a specific aim of this study. It is suggested that both tornadic and non-tornadic storms account for severe damage to property and livelihoods in the Eastern Cape and in some cases non-tornadic storms are responsible for more damage than light tornadic storms; this is often the case in severe hailstorms, straight-line winds and gust-fronts not associated with tornadic activity. It is accepted that high F-scale tornadoes are very damaging in almost all cases when high population density areas are affected. While of climatological interest, it is suggested that the tornadic/non-tornadic distinction based on information available in the storm reports remains both arbitrary and problematic and serves no particular use in this study, hence no particular attention was paid to this, except as evidence of storm severity.

6.2.2.5 Selecting comments for entering into the database

Relevant comments on each storm event were entered into the database in a "general comments" column:

- Impact/damage information: loss of life and injury, homeless people, damage to property and livelihood, infrastructural damage, livestock losses, descriptive indications of intensity (e.g. "extensive", "violent", *etc.*), areal extent, estimated Rand value of damage
- Climatological/meteorological information: hail size, wind strength, rainfall amount and duration, time and duration of storm, indication of recurrence interval (e.g. "worst storm in 30 years")

In general, most comments related to impact/damage. Where possible, quantification of the actual impact was included, e.g. "14 people killed by hailstones". In some cases, however, no actual impact figures were provided in the reports, only descriptive terms were used, such as "severe damage to trees", but these comments were included for further analysis. Comments relating to climatological/meteorological aspects were few, with the exception of hail size, which was provided using descriptive terms such as "golf ball size", "gem squash" size, *etc.* This proved helpful as this allowed actual quantification of hail size using hail diameter size in mm correlated to a hail intensity scale used by the CSIR in South Africa.

6.2.2.6 Classifying the general comments into discrete storm indicator categories

The general comments were separated into four discrete categories, *viz.* deaths, injuries, damage to property, livelihood and infrastructure, and meteorological/climatological indicators. Where possible, deaths and injuries were quantified to an exact number for each event. Some reports, however, did not provide such precise information, such as "3-6 killed" or "several injured" and in these cases this information was included as reported, as an indication of losses. For clarification, the terms "several" and "a number" were taken to represent 10 people, "few" to represent 3 people and "hundreds" to represent 500 people for the purposes of quantifying the number of deaths and injuries in the storms (*vide* Chapter 7, section 7.7). In cases where a range was reported, such as 3-6, then the maximum number was used in the calculation.

Damage to property, livelihood and infrastructure included all information in the reports relating to:

- Damage to property (huts, houses and other buildings such as schools, clinics, churches, *etc.*)
- Damage to infrastructure (roads, bridges, electricity supply, telephone lines, *etc.*)
- Livestock losses
- Crop losses
- Number of people and families affected/homeless
- Descriptive indications of intensity (e.g. "extensive", "violent", *etc.*)
- Areal extent affected
- Estimated Rand value of damage

Where possible, quantification of the damage/loss which allowed further analysis was included in the database. This proved to be reasonably easy where reports indicated the number of huts, houses, schools, *etc.* damaged or destroyed, but it was more difficult to quantify other aspects such as the extent of the area affected or crop losses, for example. Reports tended to describe such damage or loss in less specific, more descriptive terms such as "severe damage to crops" or "extensive area affected". Although not specific, such descriptions were included in the database.

Meteorological/climatological indicators included information on:

- Hail size (exact measurement in mm, or descriptive terms, e.g. "golf ball size hail")
- Wind strength
- Rainfall amount and duration
- Time and duration of storm
- Indication of recurrence interval (e.g. "worst storm in 30 years")
- Descriptive terms of storm intensity (e.g. "heavy hailstorm" or "violent downpour")

In general, there were fewer meteorological/climatological indicators compared with descriptions of damage to property and livelihood, which were present in almost all of the reports.

6.2.2.7 Deriving a storm severity scale based on observed/recorded impact

As discussed in the previous chapters, both the Fujita-Pearson tornado intensity scale and the TORRO tornado and hail intensity scales are derived from observed storm impact or physical characteristics. Relative strengths and weaknesses of these schemes have also been pointed out. It has been clearly shown that neither the Fujita-Pearson scale nor the TORRO scales are directly applicable to the South African situation, for a number of reasons. This provided the rationale for deriving a severe storm severity scale (Figure 12), which would be more applicable to the local Eastern Cape context and also to the wider South African context. A storm severity scale was therefore derived based on all available information on the 179 storms and their associated impacts. The term "severity" as opposed to "impact" was specifically chosen to provide a measure of both hazard and impact. The storm impacts were weighted so that the higher weighting had the most influence in determining the thunderstorm category or score. The researcher acknowledges that the storm severity scale is confounded to some extent by vulnerability; the impact of storms on more vulnerable communities will be greater and this will have the unavoidable outcome of affecting storm rankings to some degree.

Steps in deriving the storm severity scale

The database was carefully examined in terms of observed/recorded damage and impact. Natural breaks in the impact data most logically separated into five severe storm scale categories, which were described in the following way: TS1 (moderate), TS2 (significant), TS3 (severe), TS4 (very severe) and TS5 (devastating). The highest TS ranking of 5 was clearly demarcated in the data by four storms of devastating impact, of much greater magnitude than any of the others. In the same way, the remaining storms clearly separated into four more categories. The abbreviation "TS" was chosen to describe the scale as this is widely used in meteorology to signify a thunderstorm. It was also chosen so as not to create confusion with the Fujita-Pearson scale (the "F" scale), nor the TORRO "T" (tornado) and "H" (hail) intensity scales. Whilst these scales start at an intensity of 0 it was decided to break from this convention and to begin the TS scale at 1, again in an attempt not to conflate the TS scale with the others in use.

The following criteria, with associated quantitative/qualitative descriptors, were selected to rank the storms: loss of life, injuries, houses and buildings damaged/destroyed, other damage, livestock killed, homeless people, families affected, area affected, Fujita-Pearson tornado scale, Rand value of damage, descriptors used in reports (Figure 12).

Quantitative values for each descriptor were determined by the researcher, in consultation with disaster management officials and climatologists in the province. The researcher does, however, recognise certain shortcomings with respect to the scale. Firstly, there is inherent subjectivity associated with ranking storms where broad category ranges are used. Secondly, only absolute impact and loss values are used in the classification, as opposed to relative values (e.g. death rate per thousand of the population). Whilst adjusting losses according to relative values may provide a better indication of storm severity, the researcher asserts that it would be exceptionally difficult to arrive at such figures, given the paucity of accurate information available at such a small scale for the province.

The principle of "best fit" was applied in classifying each storm event and assigning a TS rank according to the classification scheme, using the following approach:

- The UNDP (2004) emphasises that human loss is the most reliable measure of disaster impact. Tobin and Montz (2004), too, stress that loss of life has far greater significance than loss of property. Accordingly, the relative weighting of loss of life and injury was highest, whereas qualitative damage descriptors used in reports was ranked lowest, i.e. in all cases where loss of life and injury information was provided, this was used as the single most important criterion in ranking the storms on the TS scale. For example, if 10 people were killed in a lightning storm, yet there was no other reported damage, the storm would still have been ranked TS4 (very severe). Conversely, if no people were killed in a storm, with very little quantifiable damage to houses and infrastructure, yet the report described it as "very severe", then the ranking would be a more conservative TS2 (significant) as the higher weighting would be on the nil loss of life and not the subjective, perhaps exaggerated descriptive terms used in the report.
- In cases where there was very little quantitative damage/impact information, e.g. "damage to houses", a conservative approach was used in ranking. Where events fell into two possible severity categories, then the lower was selected.
- Rand value of damage was used with circumspection in ranking as it is the experience of the researcher and other researchers (van Niekerk, pers. comm., 2006) that the value of damage provided in reports is not very reliable and is often exaggerated.

Figure 12 A severe thunderstorm severity classification based on observed/recorded impact

Weighting	Severity Scale	TS1	TS2	TS3	TS4	TS5
Highest	Description	Moderate	Significant	Severe	Very severe	Devastating
	Damage / Impact	**Damage / Impact**	**Damage / Impact**	**Damage / Impact**	**Damage / Impact**	**Damage / Impact**
	Loss of life	Nil	1 to 2	3 to 5	6 to 14	15 and more
	Injuries	Nil	1 to 3	4 to 10	11 to 50	More than 50
	Houses/buildings damaged/destroyed	Few (1-5)	Many (6-100)	Lower hundreds	Middle hundreds	Higher hundreds/thousands
	Other damage*	Moderate	Significant	Severe	Very severe	Devastating
	Livestock killed	Some (1-10)	Many (11-100)	Lower hundreds	Middle hundreds	Higher hundreds/thousands
	Homeless people	Some (1-20)	Many (21-100)	Lower hundreds	Middle hundreds	Higher hundreds/thousands
	Families affected	Some (1-10)	Many (11-20)	21-100	101 to 200	More than 200
	Area affected	Very localised (e.g. a farm/village)	Localised (few farms/villages/1 town)	Wider (more villages/towns)	Wider (more villages/towns)	Extensive, disaster area proclaimed
	Fujita-Pearson Tornado Scale	F0	F0/F1	F1/F2	F2/F3	F2/F3/F4
	Rand value of damage	Hundreds to low thousands	Higher thousands	Hundreds of thousands	Millions	Many millions
Lowest	Descriptors used in reports	Moderate, localised damage	Destructive, considerable damage	Severe/extensive damage, violent	Very severe damage	Devastating, disaster, incalculable damage

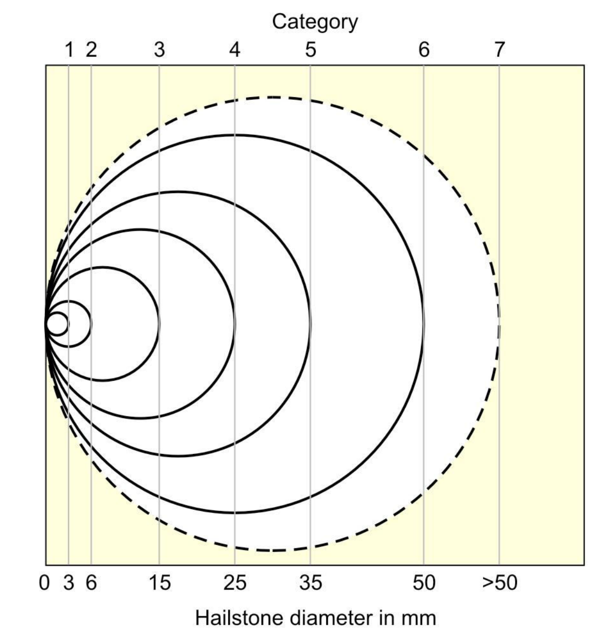
* includes infrastructural damage to roads, bridges, electricity lines, vehicles, crops, *etc.*, which are difficult to quantify

- Descriptors used in reports, e.g. "great havoc" were treated with caution, especially in cases where there was no corroborating evidence in terms of actual impact/damage. As such, descriptors were allocated the lowest weighting of all the criteria.
- Tornadoes already classified by Goliger *et al.* (1997) and van Niekerk and Sampson (1999) were assigned a TS rank based on their F scales and, where possible, reported damage. In cases where there was no further impact/damage information available for high F scale tornadoes then more conservative TS rankings were given, e.g. Fort Cox (F3 tornado) was assigned a TS3 ranking.
- Careful attention was given to the distinction between houses and buildings *destroyed* or *damaged*. In cases where the majority of houses were destroyed as opposed to damaged then higher TS rankings were assigned. The researcher accepts that rural and informal dwellings made from less robust building materials such as wood, mud, thatch and corrugated iron are more susceptible to damage in the face of severe storms, compared with more resilient urban structures constructed from brick and mortar. Accordingly, one might reasonably expect more rural/informal houses to be damaged or destroyed during a severe storm event, which makes assigning a TS rank based purely on house and building damage problematic. Fortunately, in most cases, reports on housing and building damage were substantiated by other damage descriptors such as loss of life and injury, infrastructural and crop damage, which alleviated the problem to some degree.
- In cases where there was only meteorological information, e.g. "200 mm" and no actual damage/impact information, these were deemed "unclassified", shown as "U" in the database.
- The storm rankings were entered into the database.

6.2.2.8 Ranking hail storm intensity based on the CSIR hail intensity scale

The CSIR hail intensity scale has been discussed previously in Chapter 3 (section 3.6.2). As previously stressed, meteorological/climatological indicators found in the reports were scarce and this militated against ranking all the storms based on such criteria. However, descriptions of hail size found in the reports were generally reliable and accurate and in many cases an actual indication of hail size was provided, either in diameter size in mm or as a descriptor, e.g. "dove egg size" or "golf ball size". In cases where descriptors referred to the egg size of different birds, actual egg sizes in mm were obtained in *Roberts' Birds of Southern Africa* (MacLean, 1985) to enable objective classification. Accordingly, it was decided that it would be useful to rank these storms against the hail size categories/intensities used in the CSIR study (Rae, 2005). A total of 32 storms provided information which was quantifiable and these storms were subsequently ranked from intensity 1 to 7, based on maximum hail size reported in the storms. These rankings were entered into the database for further analysis. Figure 13 shows the hail size categories/intensities and descriptions used in the classification.

Figure 13 Hail size categories/intensities and descriptions



Category	Diameter (mm)	Description
1	3	Rice
2	6	Pea
3	15	Grape, marble
4	25	Walnut, dove's egg
5	35	Golf ball, pigeon's egg
6	50	Hen's egg
7	>50	Larger (duck's egg, apple, cricket ball, tennis ball, gem squash)

Adapted from Rae, 2005

6.2.3 Analysing the storm data in a GIS (ArcView 9.1)

Two geospatial databases were developed for producing illustrative maps and themes:

1. All storm events from 1897-2006
2. Vulnerability indicators at a municipal scale, using data obtained from Statistics South Africa (2006) and *SA Explorer* (2005)

GIS-generated maps and graphs (using Excel) showing the following themes were produced for detailed discussion and analysis:

Hazard characteristics

- Distribution/frequency of reported storms

- Seasonality of reported storms
- Time of occurrence of reported storms
- Storm/hazard type
- Severity/impact of reported storms
- Total number of injuries and deaths
- The pattern of lightning and hail hazard

Vulnerability indicators

- Socio-economic
  - population density
  - education and income level
  - age-sex profile
- Physical/infrastructural
  - type of dwelling
  - road density
  - access to communications/early warning capacity
- Composite vulnerability

Risk patterns

- Overall risk (R = H x V)
- Risk patterns + hazard threat
- Risk patterns + injuries
- Risk patterns + deaths

The following section provides further explanation of and justification for selecting the above themes.

6.2.3.1 Hazard characteristics

1. Distribution and frequency of reported storms

   This theme was chosen to represent the geographic distribution and frequency patterns of all reported storms in the Eastern Cape from 1897 to 2006. The primary purpose was to demarcate and analyse geographic areas of low and high hazard frequency/high climatological threat and to analyse variations in the inter-annual distribution of storms. A secondary purpose was to compare the frequency of reported storms for two time periods, *viz.* 1897-1991 and 1992-2006 in order to gain some indication of the effect and geographic distribution of improved reporting during the latter time period. The dividing dates of 1991/1992 are clearly demarcated in the database where 1992 shows the starting point of more reliable and consistent storm reports from the former Ciskei and Transkei areas of the province.

2. Seasonality of reported storms

   Seasonality refers to the distribution of reported storms during the year, expressed in months and seasons (summer, autumn, winter, spring). The purpose of this analysis was to demarcate peak, low and high frequency months. The seasonal distribution of storms for the two time periods mentioned above was also analysed to determine any differences.

3. Time of occurrence of reported storms

   The reported time of day when the storms occurred was analysed in order to determine the peak times for the time series.

4. Storm/hazard type

   The frequency of all hazard types (tornado, wind, hail, lightning, flash flooding) reported in the 179 storms was calculated for the time series. The purpose was to determine the relative frequency of each hazard type reported.

5. Severity/impact of reported storms

   The method used to rank each storm according to a severity/impact scale (TS1-TS5) has already been explained in this chapter. This theme was selected to determine the relative frequency of reported storms in the five severity classes and to analyse the frequency, geographic distribution and impact of storms in each class. Furthermore, this would allow comparisons to be made amongst the five classes regarding frequency and distribution.

6. Total number of injuries and total number of deaths

   The total number of injuries and the total number of deaths reported in the 179 storms was mapped in order to show their geographic distribution and frequency. The purpose was to demarcate geographic areas and to analyse patterns where injury and loss of life has been particularly high for the time series.

7. The pattern of lightning and hail hazard

   The severe impact of lightning and hail was documented in detail and in many cases quantified in the storm reports; this allowed for detailed individual analysis of lightning and hail patterns. Accordingly, the frequency, distribution, seasonality and impact of lightning and hail was presented and analysed. In addition, reported hail size was mapped and analysed, as discussed previously.

6.2.3.2 Vulnerability indicators

Eleven individual socio-economic and physical/infrastructural indicators were selected to represent the vulnerability of various geographic populations to the impact of storms. These were chosen in accordance with those indicators which have proved to be significant in comparable vulnerability studies (*vide* Chapter 5, section 5.3) and with specific relevance to the study context within the Eastern Cape. The importance of ground-truthing these indicators has already been emphasised in this chapter. Field research and interviews with affected persons and communities in high-risk areas in the province confirmed the researcher's assumptions regarding priority vulnerability factors, in particular poverty, inadequate housing, remoteness and the lack of early warning/communication facilities. Respondents in the remote rural areas also commented on the lack of service delivery by state and provincial departments and on the high incidence of illness in many villages, particularly tuberculosis and other AIDS-related illnesses; whilst these must be noted as general vulnerability factors, they were not included in this study as they are not specifically relevant to severe storm hazard.

Vulnerability data were obtained primarily from Statistics South Africa (2006), supplemented with data obtained from *SA Explorer* (Version 3.0, 2005) to produce thematic maps at a municipal scale (*vide* Chapter 8). Socio-economic and physical/infrastructural data obtained from Statistics South Africa (2006) was based on the previous 2001 national census conducted in South Africa, which is reported by Statistics South Africa to have a 95% confidence level. Supplementary data were obtained from *SA Explorer* (2005), which provides recent geographical, electoral and demographic data on South Africa obtained from the Municipal Demarcation Board. Importantly, Census 2001 information from Statistics South Africa is incorporated into *SA Explorer.* The researcher accepts that whilst the data obtained from both sources may not reflect the *exact* present conditions in the Eastern Cape, the sources and data were chosen to represent the most accurate, reliable and current statistics available for the whole province – more recent, smaller scale socio-economic and demographic studies may have been completed in the province, but this would not be helpful in providing large-scale provincial data for this study. A study conducted by Statistics South Africa (2002), which examined the living conditions in the impoverished eastern district municipalities of OR Tambo, Alfred Nzo, Chris Hani and Ukhahlamba provided useful supplementary socio-economic data at a more local level.

The geographic units of analysis chosen for this study were local municipalities and districts. The Eastern Cape comprises 38 local municipalities, amalgamated into six district municipalities and one metropolitan municipality (*vide* Figure 40 in Chapter 8). Local municipalities in a South African and Eastern Cape context are an amalgamation of previously small towns and rural communities which now form enlarged local jurisdictions. District municipalities, on the other hand, are facilitating bodies at a higher level which have primarily a watchdog, coordinating and funding role for a number of local municipalities falling within their area of jurisdiction. Disaster management in the province is coordinated at provincial and district level, yet local municipalities have responsibility for managing disaster management activities within their own municipal areas. Census data are available at a smaller scale of individual electoral wards (*vide* Figure 39 in Chapter 8, section 8.3), yet this is not particularly useful for this study. As such, the most appropriate spatial unit for analysis in this study is at municipal scale.

Assumptions regarding vulnerability are in brackets next to each indicator. Further explanation regarding each indicator is provided where appropriate.

1. Population density (number of persons/km^2) (high density is associated with high vulnerability of the population as a whole, i.e. high density areas do not necessarily put an individual at higher risk, but it does increase the risk of more people being affected by a storm event)
2. Level of education (% of population with no education) (low levels of education are associated with high vulnerability). People with no education would be highly disadvantaged in terms of understanding and responding to early warnings and would have no scientific understanding of severe storms and their related impacts.
3. Level of income (% of households earning equal to or less than R6 000 per annum) (low income levels are associated with high vulnerability). The figure of R6 000 per

annum or R500 per month was decided as this represents a combined household income which is very low and would most likely reflect the situation in the vast rural areas of the province where many households rely solely on income from welfare/pension grants and child allowances to survive. The poorest are more likely to sustain absolute losses and have little in reserve to aid their recovery (Lewis, 1999).

4. Percentage of young children and old people (combined % of population 0-9 years and older than 65 years) (young children and old people are more vulnerable)
5. Female/male ratio (number of women: number of men) (females are more vulnerable)
6. Percentage of households living in shacks (poorly constructed shacks in informal settlements are more vulnerable)
7. Percentage of households living in traditional houses (houses constructed from mud, wood, thatch and corrugated-iron are more vulnerable)
8. Road density (km/km^2) (areas with low road density are more vulnerable). Remote villages in areas where road linkages are poor will be difficult to reach by emergency services in the event of a storm.
9. Percentage of households with no access to a telephone (landline and cellular)
10. Percentage of households with no radio
11. Percentage of households with no television. (Communities with no access to a telephone, radio or television are more vulnerable as they will not be able to receive early warnings and forecasts)

It must be stressed that although the above indicators are likely to be highly correlated, each indicator on its own will contribute to individual or community vulnerability and therefore can be considered separately. Noble *et al* (2006) comment on the difficulty in assigning relative weights to indicators to indicate a measure of importance, in particular the inherent subjectivity involved in such a process. In the absence of any convincing evidence that any one of the indicators was relatively more important than any other it was decided to apply an equal weighting to the 11 vulnerability indicators.

For each of the above 11 indicators 6 classes were selected, ranging from the lowest to the highest values. The same classes were used for each municipality. Using natural statistical breaks (the Jenks method), classes were based on natural groupings inherent in the data. The GIS identifies break points by picking the class breaks that best suit similar values and maximise the differences between the classes. The features are divided into classes whose boundaries are set where there are relatively big jumps in the data values (ArcView 9.1, 2004). In addition, a composite vulnerability map was generated for each municipality by integrating the thematic maps for all indicators, using the intersect method of GIS. The composite vulnerability index of the integrated layers was calculated for each municipality by using the following formula:

$$VI = \frac{\text{pop} + \text{edu} + \text{inc} + \text{age} + \text{fm ratio} + \text{shacks} + \text{trad} + \text{road} + \text{phone} + \text{radio} + \text{tv}}{\text{number of themes (11)}}$$

The municipalities were classified into five classes according to their VI value, from lowest to highest vulnerability (1 = low, 2 = moderate, 3 = high, 4 = very high, 5 = extremely high). An additive relationship among the variables, as opposed to an multiplicative one, was chosen as this was intuitively reasoned to be a more cautious approach; multiplying the 11 variables would have had an excessively compounding effect.

6.2.3.3 Risk patterns

Risk patterns were mapped at a municipal scale according to the formula R = H x V, where H = the number of reported storm events for each municipality from 1897-2006, and V = the composite vulnerability for each municipality defined above. A scaled-down risk index from 1 to 5 was calculated for each municipality using the following formula:

$$RI = \frac{H\ .V}{\text{number of classes (5)}}$$

The researcher chose H to represent the total number of storms, rather than the number of storms by TS rating, in order to avoid the problem of compounding vulnerability in the calculation.

The municipalities were classified into five classes according to their RI value, from lowest to highest risk (1 = low, 2 = moderate, 3 = high, 4 = very high, 5 = extremely high).

The following thematic maps were prepared and analysed:

1. Risk patterns

   The purpose of this map was to demarcate the highest and lowest areas of storm risk in the province and to analyse the general patterns and trends of risk shown.
2. Risk patterns + storm severity

   The total number of reported storms in the more severe categories (TS3-TS5) was overlain on the risk map to examine the relationship between high risk areas and areas of high storm impact. The assumption is that high risk areas should correspond well with areas of high storm impact, based on the historical data.
3. Risk patterns + total number of injuries
4. Risk patterns + total number of deaths

   The total number of injuries in all reported storms from 1897-2006 (Figure 32 in Chapter 7) was overlain on the risk map and similarly for the total number of deaths (Figure 33 in Chapter 7). The assumption is that areas of high numbers of injuries and deaths should correspond well with the high risk areas.

6.3 Summary

This chapter has outlined the methods used in conducting this study. The methods were chosen to reflect the conceptual framework and the assessment framework selected for this study as discussed previously in Chapter 1 (section 1.5) and Chapter 5 (section 5.5) respectively. The methods set out in this chapter are scientifically rigorous, yet the researcher acknowledges that some degree of subjectivity is intrinsic to any assessment methodology; this aspect is unavoidable but every effort has been made to minimise subjective bias by using objectively quantifiable assessment criteria, where possible. Similarly, the researcher has made every effort to verify the accuracy of storm reports by consulting multiple sources of information. In addition, the process of ground-truthing by means of site investigations, field research and interviews was undertaken in high risk areas to verify storm reports and to investigate vulnerability factors *in situ.* In spite of these measures to improve data quality and reliability, the researcher acknowledges that some reporting error is inherent in this type of study, which is based predominantly on data derived from secondary sources; this will inevitably lead to some degree of data unreliability.

CHAPTER SEVEN: THE ANALYSIS OF HAZARD

When I saw Inkanyamba coming, I thought the end of the world had come.
Shepherd Mhlawuli, resident of Sitebe village near Umtata, July 2006

7.1 Introduction

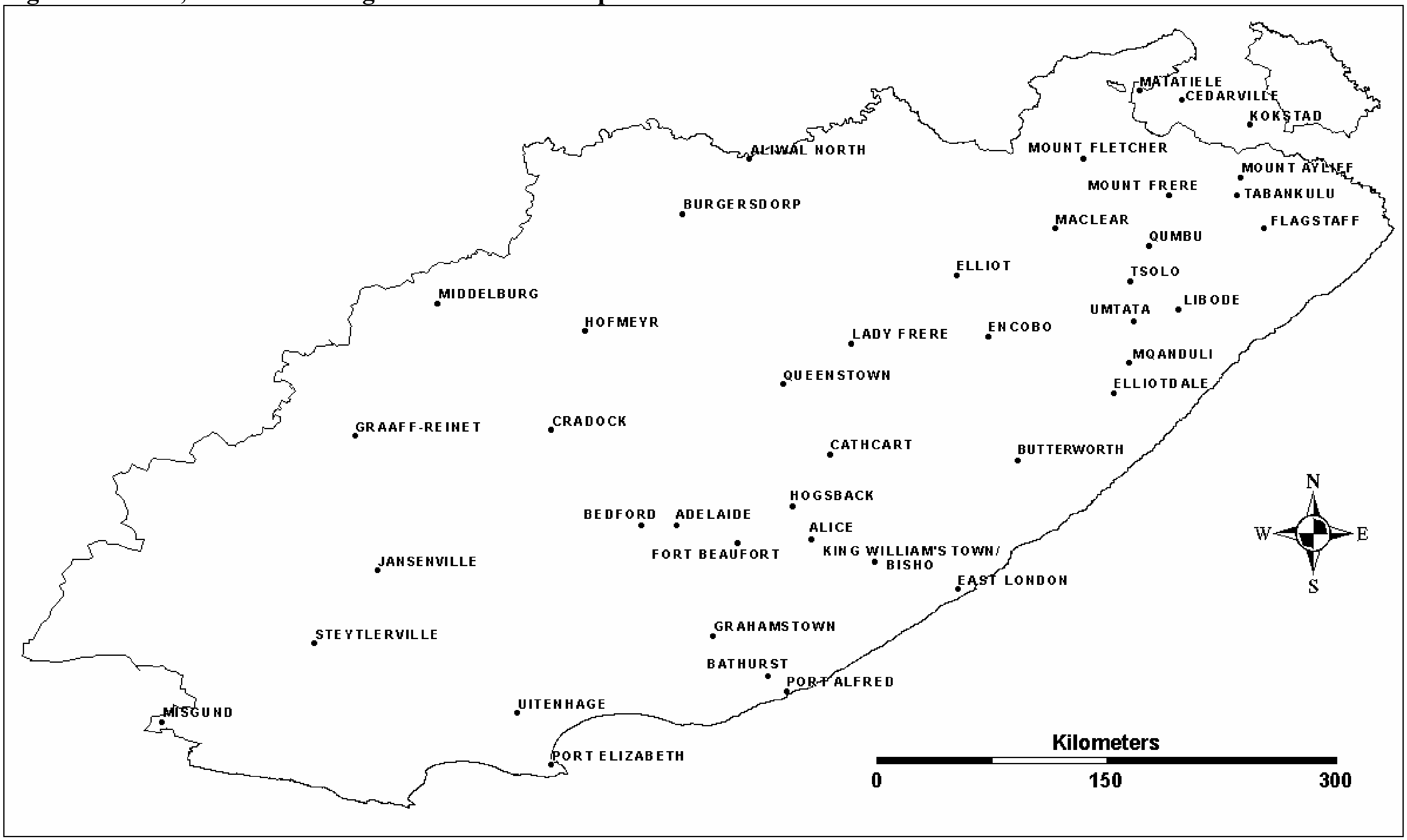
The purpose of this chapter is examine the physical dimensions (parameters) of severe storm hazard and associated impacts in the Eastern Cape with respect to:

- Distribution
- Frequency
- Seasonality
- Time of occurrence
- Storm severity

The dataset compiled on severe storms from 1897-2006 (CD enclosed) and the GIS generated maps are analysed and presented in order to determine the broad spatial and temporal patterns of hazard for the province. This gives an indication of the pattern of *climatological threat* from severe storms in order to establish a broad hazard profile for the province. The main cities, towns and villages in the Eastern Cape, which are referred to in this chapter, are shown in Figure 14. Certain place names in the Eastern Cape have changed during 2006, e.g. Umtata has changed to Mthatha, while Bisho has become Bhisho, in order to reflect the original Xhosa spelling of these places more accurately. The researcher has decided to retain the former names as most of the maps for this thesis were produced prior to any changes.

Tobin and Montz (1997; 331) assert that "Researchers have frequently compartmentalized the three crucial components of the hazard complex: physical characteristics, political and economic factors, and social or situational characteristics" but urge that "*it is necessary to put them together in an attempt to develop our understanding of the relationships between components as they define risk and vulnerability*" (author's emphasis). Whilst this chapter will address only the

Figure 14 Cities, towns and villages of the Eastern Cape



hazard/impact dimension of severe storms, the following Chapter 8 will investigate key vulnerabilities arising from economic, social and physical/environmental factors. The interrelationships between the severe storm hazard and the key vulnerability patterns will be explored in Chapter 9 to determine overall patterns of risk, using the equation R = H x V.

In addition, the point has been made previously in Chapter 3 that severe storms are compound hazards consisting of damaging wind, lightning, hail and flash flooding, in various combinations. The severity of storm impact is often exacerbated by this compound effect, so it is perhaps best to approach the analysis in this chapter from the perspective of severe storm hazard as a whole and not to separate the single elements for detailed analysis. It is, however, instructive in certain cases to examine the spatial and temporal characteristics and impact potential of a single element, such as hail or lightning, especially where the impacts are shown to be very damaging. This has been done where the information in the historical dataset allows reasonable confidence in the conclusions drawn.

Certain parameters such as duration and speed of onset are not discussed in this chapter as the reports in the dataset provided very little information which could be reliably analysed.

A currency conversion table (Table 2) has been included to facilitate comparison of Rand value damage with commonly used international currencies.

7.2 Distribution and frequency of storms

Figure 15 shows the distribution and frequency pattern for the 179 storms (all elements) for the historical period 1897-2006.

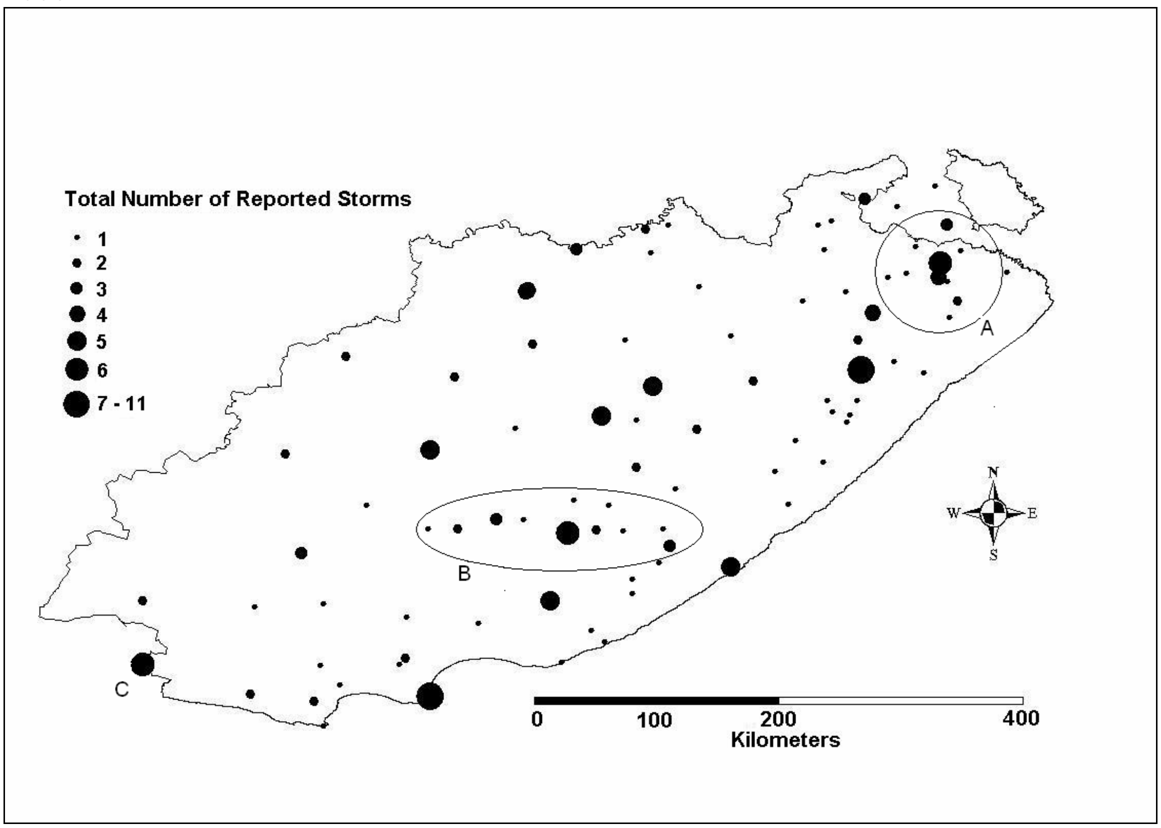
Table 2 Currency conversion table

	ZAR	USD	EUR	GBP
1 USD	7.40318	1.00000	0.783821	0.524322
Inverse	0.135077	1.00000	1.27580	1.90723
1 EUR	9.44498	1.27580	1.00000	0.668930
Inverse	0.105876	0.783821	1.00000	1.49492
1 GBP	14.1195	1.90723	1.49492	1.00000
Inverse	0.0708239	0.524322	0.668930	1.00000

* As of 01/11/2006

Source: xe.com, 2006

Figure 15 Distribution and frequency of severe storms in the Eastern Cape: 1897-2006



7.2.1 Areas of high frequency

Two patterns of higher storm frequency are evident. Firstly, frequencies are generally shown to be highest in the metropolitan areas and larger central towns (East London, Port Elizabeth, Umtata, Grahamstown, Queenstown, Cradock, *etc., vide* Figure 14 for individual place names). This is due to the fact that, given high population densities in these areas, there is a greater chance that a number of people will be affected. In addition, higher storm frequencies are often a reflection of better reporting in more populated areas, where infrastructure and mechanisms exist to record storm events in various publications, e.g. newspapers, disaster management reports, meteorological reports, *etc.* Port Elizabeth, for example, the largest metropolitan area in the province, has the highest frequency of 11 reported storms for the province as a whole, whilst Umtata, a smaller urban centre, yet important node in the north-eastern area, has 10. It is generally accepted that the likelihood of storms of all magnitude and severity being reported and recorded in larger urban areas is much higher than in sparsely populated rural areas.

Secondly, some areas situated far from the densely populated urban areas show high to very high frequencies. One area of particular interest and activity is Mount Ayliff – Tabankulu (marked A in Figure 15) in the extreme north-east, which has experienced a very high frequency of storms. The area may be best described as consisting of a few larger rural villages, surrounded by numerous smaller villages in a very densely populated area. Although many people inhabit the north-eastern parts of the province, it is generally poor and under-developed, which would have resulted in under-reporting of storms in the past (*vide* Figure 41 to Figure 51 in Chapter 8). The researcher asserts that had better structures been available for accurate reporting, the frequency of reported storms in the Mount Ayliff and Tabankulu area would have been considerably higher. It is contended that this would be the case too for the whole of the north-eastern area of the province and the southern parts of KwaZulu-Natal around Kokstad and Matatiele.

From a purely physical perspective, it is postulated that orographic forcing from local mountain ranges and the southern Drakensberg range of the Great Escarpment (Figure 16), combined with climatological forcing (higher atmospheric moisture, location of the upper jet stream and periodic spells of anomalous warming of the Agulhas stream along the eastern coastline) enhance severe storm development in these north-eastern areas, including Mount Ayliff, Tabankulu, Umtata and the surrounding rural area (Rouault *et al.*, 2002). Further research needs to be conducted into the specific climatology of the region as there is still considerable uncertainty surrounding the exact reasons for the high frequency of storms in these areas; this research falls beyond the scope of this thesis.

A second area of particular interest and activity (marked B in Figure 15) is shown in a line running west-east from Cookhouse – Fort Beaufort – Alice – Hogsback – Bisho (King Williams Town). In this case, the mountains of the Winterberg range of the southern escarpment (Figure 16) are likely to play a role in providing strong orographic forcing to produce more convective storms in the area (van Niekerk, pers. comm., 2006).

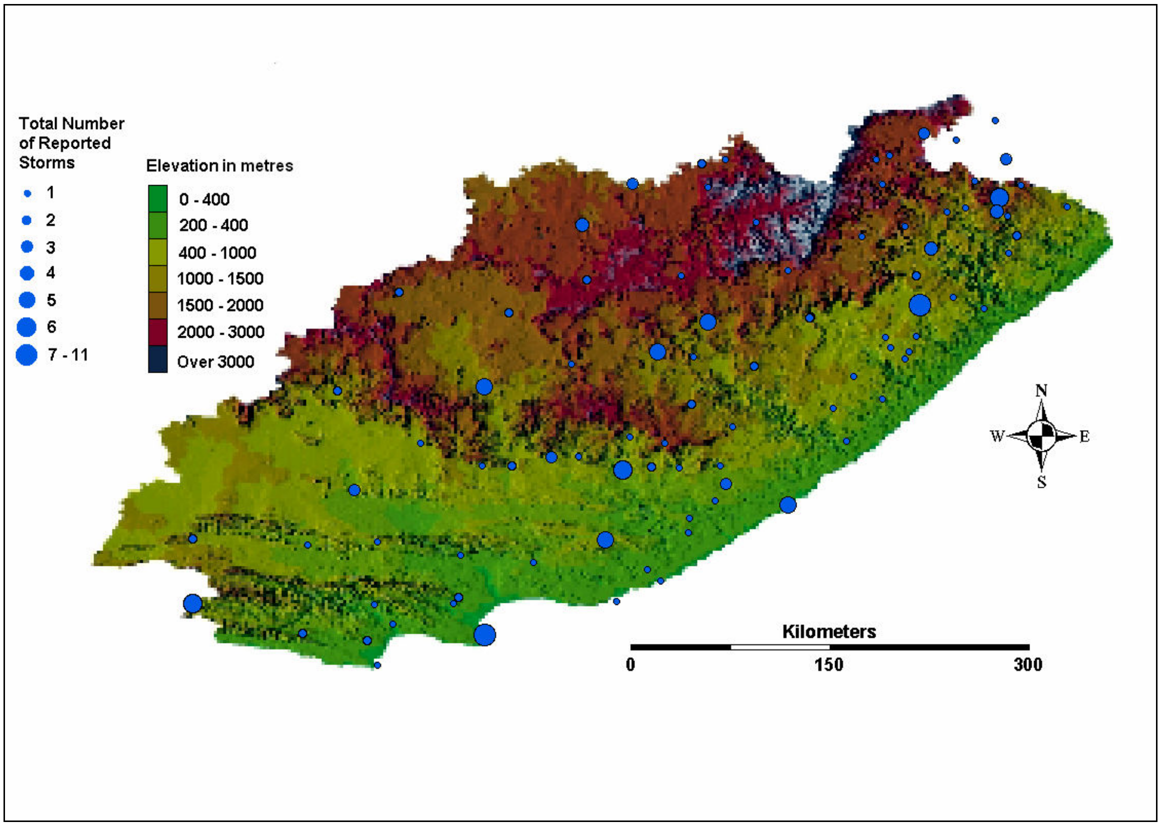
A third high frequency area is noticeable in the extreme south-west at Misgund (marked C in Figure 15), which is located in the Langkloof Valley, an important deciduous crop area in the province. Devastating hailstorms have occurred regularly in this area in the past.

7.2.2 Areas of low frequency

The north-western and western parts of the province exhibit generally lower frequencies of storms compared with the eastern areas. This appears to be combination of climatological factors (the western areas of the province have less moisture in the atmosphere, *etc.*) and under-reporting where the population densities are low. Unfortunately, many storms go unnoticed and unreported, or are simply never recorded in the more remote, sparsely rural areas (de Coning and Adam, 2000). Goliger *et al.* (1997) confirm this with regard to tornado distribution patterns in the sparsely populated western areas of South Africa.

There are, however, some localised areas of higher frequency in the west and north-west, specifically in the main towns such as Cradock and Jansenville, which as mentioned

Figure 16 Distribution of severe storms from 1897-2006 in relation to major relief features



previously is more likely a function of better reporting rather than any climatological factors favouring storm development (Goliger *et al.*, 1997).

7.2.3 The geographic distribution of storms for 1897-1991 and 1992-2006

Analysis of the dataset reveals that more reliable and consistent reports of storms in the former Transkei and Ciskei areas of the province commenced from 1992 onwards. Prior to 1992 reports were almost exclusively found in the western areas of the province. Figure 17 and Figure 18 contrast the geographic distribution of storms for the two time periods within the whole time series, *viz.* from 1897-1991 and from 1992-2006. Figure 17 provides clear evidence of the very low number of reported storms in the eastern areas (former Transkei and Ciskei) for the earlier time period. In comparison, Figure 18 shows the high frequency of reported storms in the eastern areas for the latter time period. Given that reporting and recording of storms in the eastern parts of the province has improved considerably since 1992, it is suggested that Figure 18 provides a more accurate and

Figure 17 Distribution and frequency of severe storms: 1897-1991

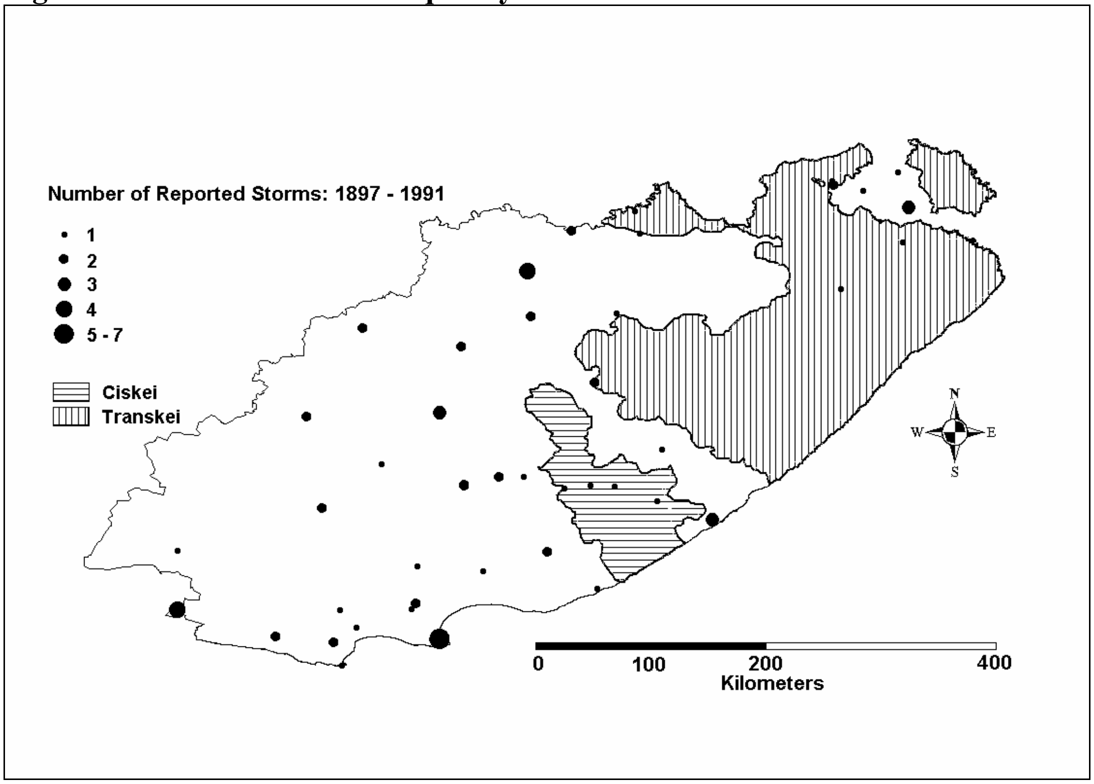
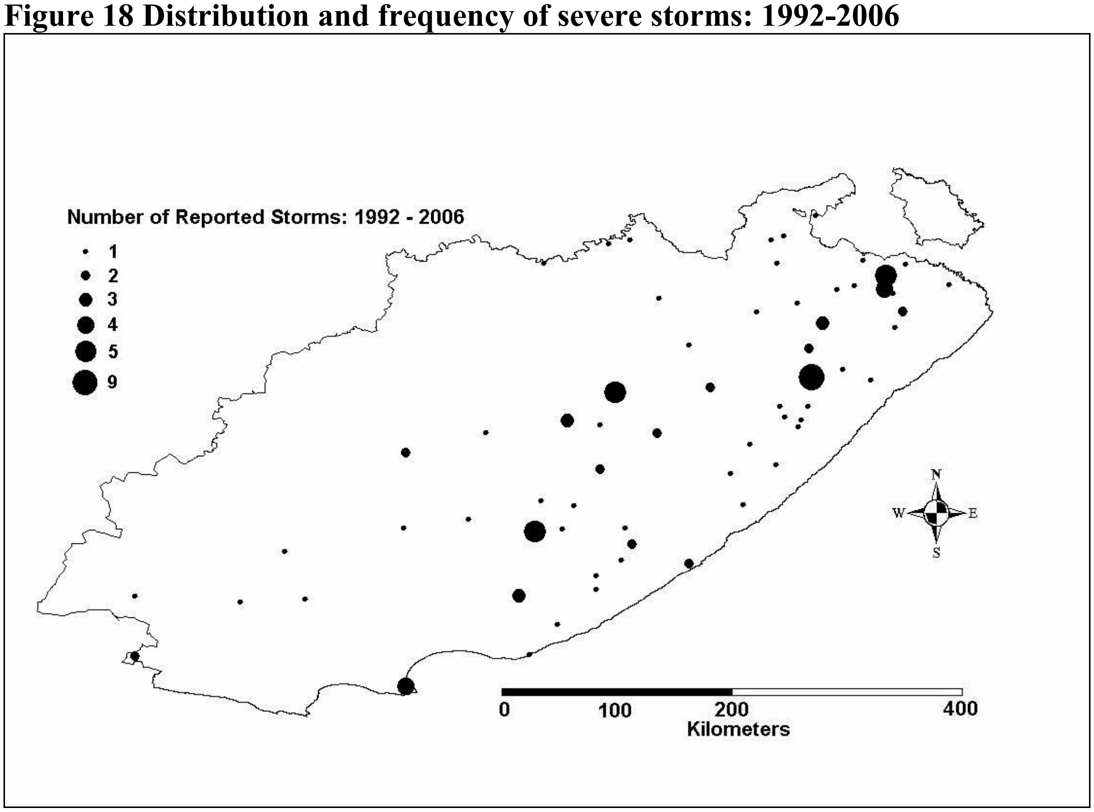


Figure 18 Distribution and frequency of severe storms: 1992-2006



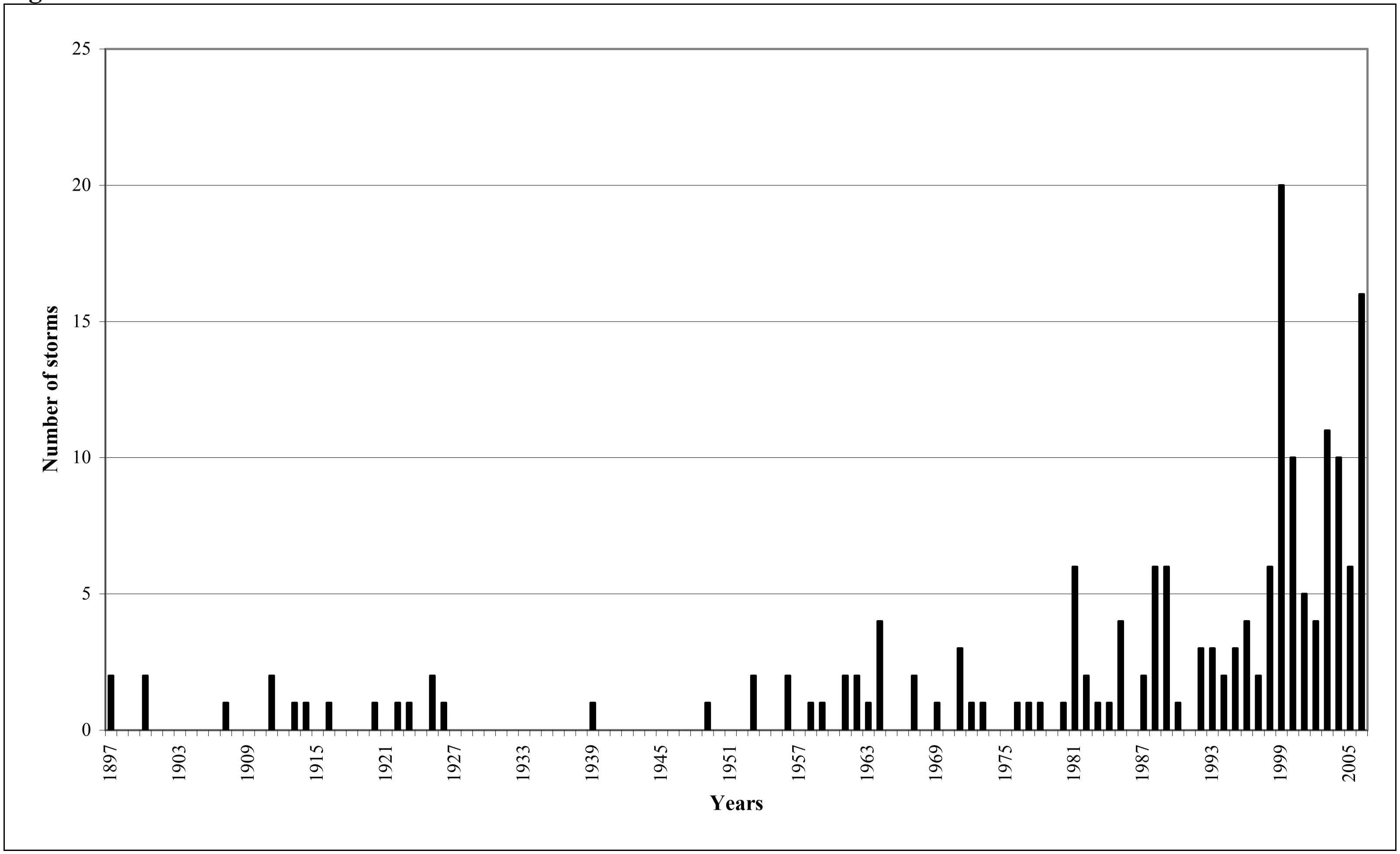
reliable representation of the actual incidence of storms for the entire province, albeit for a short time period.

7.2.4 Annual distribution of reported storms: 1897-2006

Figure 19 shows the historical trend in severe storms from 1897-2006. It further shows an increase in the number of reported storms for the 110-year time series. It is suggested that the marked increase since approximately 1981 can be attributed more to better reporting and recording of storms in the province, rather than to any absolute increase in the number of storm occurrences. Similarly, the low frequency of storms and the long intervals between events is most probably a result of a lack of consistent reporting during the earlier period of the time series. The researcher believes that it would be erroneous to make any assumptions regarding any absolute increase in storm incidences since 1981. A much longer time series consisting of data based on accurate and reliable reports is required before any definite climatological trends can be established. It is worth noting, though, that a much better consistency in reporting is evident in Figure 19 from 1992 to 2006, for which there are no years with nil reports. On average, it is most unlikely that any particular year would experience no storms at all – this is more likely to be a reflection of inconsistent reporting in the past. The data also suggest that from 1992 onwards significantly more storm reports started being made from the former Transkei and Ciskei areas. Reporting has been particularly improved in the remote rural areas in the north-east, which are more likely to have a higher frequency of storms based only on climatological reasons. The improved consistency in reporting is likely to be in part a result of the new political dispensation in South Africa, which came about in 1994. Van Niekerk and Sampson (1999) use 1994 as the point of departure in their analysis of tornadoes in the Eastern Cape. In particular, the self-governing territories of Ciskei and Transkei were re-incorporated into the Eastern Cape Province and received greater attention and support from the new ANC government from 1994 (Simon and Ramutsindela, 2000).

Within the 110-year time series, the 1998/1999 summer season produced 26 storms in the province, the highest number of reported storms for a summer season on record. Van

Figure 19 Annual distribution of severe storms: 1897-2006



Niekerk and Sampson (1999) make a strong case for increased awareness and reporting playing a major role in this increase, in particular the increased publicity arising from former president Nelson Mandela's narrow escape during the Umtata tornado in December 1998. The authors admit that although the number of reported events was exceptional for this period, they could not prove with any scientific certainty whether this was a climatological "freak" season.

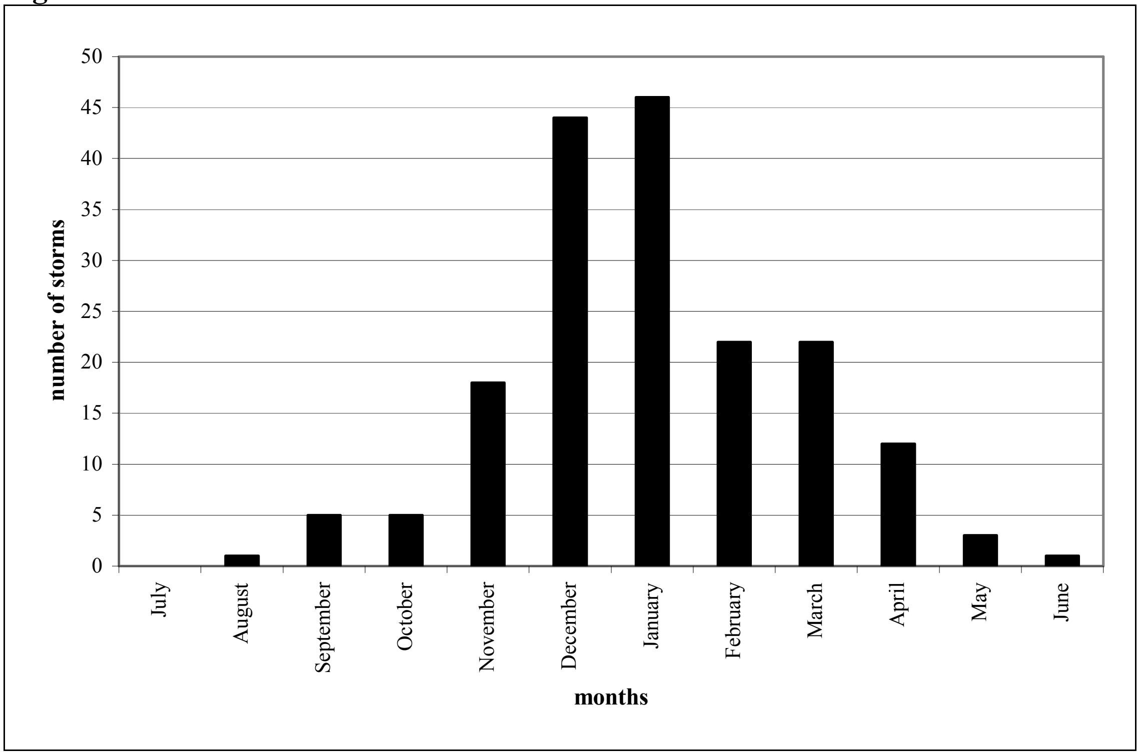
Hundermark's (1999) study on tornadoes in South Africa from 1900-1999 reveals a similar pattern of sporadic reporting until 1946; thereafter a rapid increase is observed. Again, the low incidence of events prior to 1946 can be attributed more likely to erratic reporting. Goliger *et al.* (1997) confirm that the data they compiled on tornadoes for the period 1905-1945 are erratic and inherently unreliable. Significantly, very few events in the former Ciskei and Transkei are recorded in both Hundermark's (1999) and Goliger *et al.'s* (1997) studies, which provides a misleading indication of the actual number of tornadoes occurring in the region.

In conclusion, storm frequency provides a useful indication of the general geographic pattern of hazard. However, storm frequency combined with storm severity will provide a fuller understanding of hazard threat and this will be examined in detail further in this chapter.

7.3 Seasonality of storms

Figure 20 shows a distinct seasonal pattern of the 179 severe storm occurrences from 1897-2006. January (46) and December (44) represent the two peak summer months, where risk is highest. Significantly, 50% of storms occur during these two months. February (22), March (22), April (12) and November (18) are high to moderate frequency months. These six high frequency months account for 92% of reported storms from 1897-2006. The storm season starts in September/October, increases through November, peaks in December/January, and decreases again to low frequencies in May/June. This pattern corresponds with the time of the year when convective heating is at its highest in the province, therefore high storm frequencies are to be anticipated.

Figure 20 Seasonal distribution of severe storms: 1897-2006



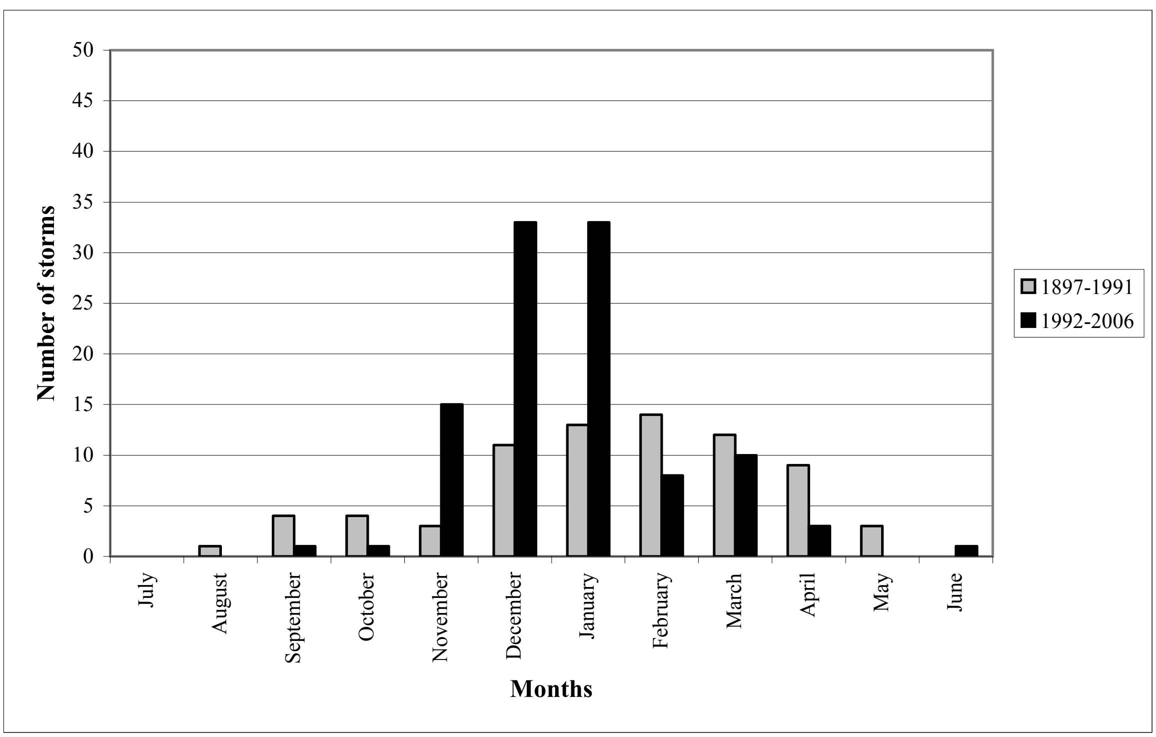
Although April shows the lowest frequency during this six-month period, it is still surprisingly high considering that convectional heating has decreased substantially by then. This may be explained in part by the fact that there is still sufficient residual heat in the atmosphere to promote storm development; this combined with cooler lower-level undercutting from the passage of cold fronts which have started to move further northward in autumn, may provide the necessary trigger action. There is clear evidence from the graph that a number of severe storms can still occur well past the peak summer months and that the threat of storms is not substantially reduced until May.

Only 8% of storms have occurred historically from May to October. This is to be expected as convectional heating during this time from late autumn to mid-spring is lowest so there can be very little associated storm development. The three winter months of June, July and August represent the lowest risk. It is postulated that the few storms which do occur during these months are associated with upper air perturbations, which occur in advance of cold fronts moving over the subcontinent from west to east, e.g. the very rare, devastating storm which struck the Maclear and Ugie area in 1994 occurred anomalously in June.

The seasonal distribution of storms for the province compares reasonably well with Goliger *et al.* (1997) and Hundermark's (1999) findings on tornadoes in South Africa. Their studies show similarly clearly defined summer maxima and winter minima. There were, however, a significant number of tornadoes occurring in spring and early summer (September-November) and late autumn (May), which shows a different pattern from this study.

Figure 21 compares the seasonal distribution of storms for two time periods within the whole time series, *viz.* 1897-1991 and 1992-2006. The former time period reflects storms which have occurred predominantly in the western parts of the province, while the latter time period reflects those which have occurred predominantly in the eastern areas.

Figure 21 Seasonal distribution of storms: 1897-1991 and 1992-2006



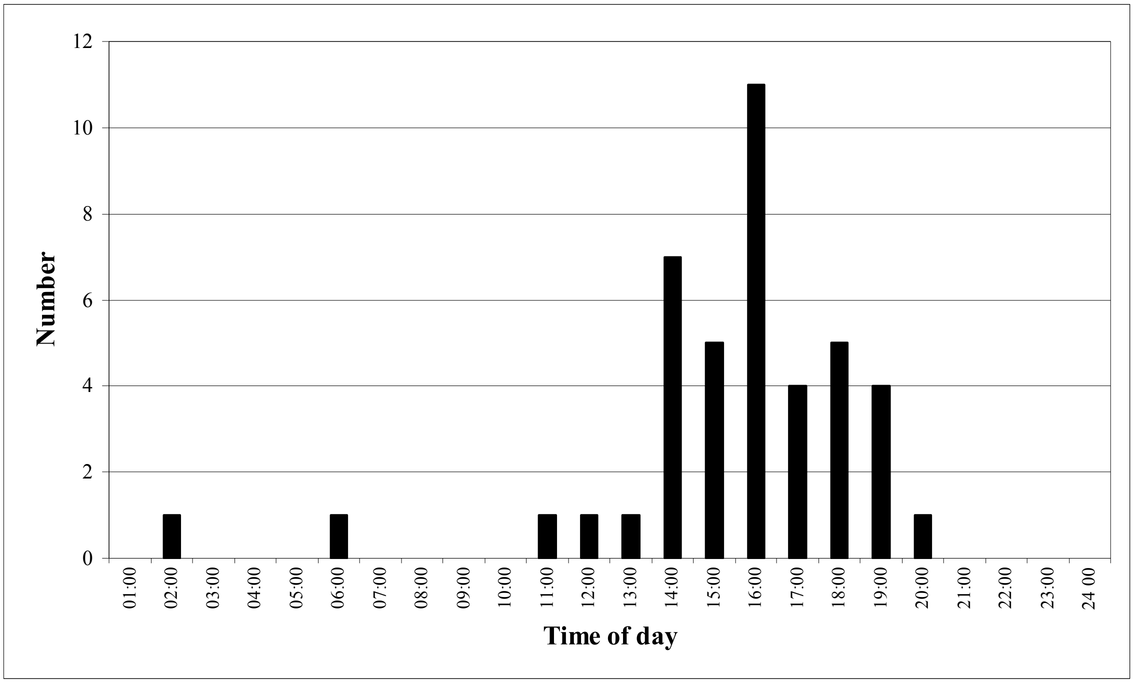
The graph shows a marked summer maximum and winter minimum for both time periods. However, there are important differences which need comment. The earlier time period from 1897-1991 shows a later peak period of storm occurrences from January-February-March, while the later time period from 1992-2006 peaks earlier from November-December-January. In addition, the earlier time period shows storm occurrences extending well into autumn (April and May), while this is not seen in the later time period. It is suggested that these seasonal differences between the two time periods may be explained primarily by the west-east geographic distribution of storms during the time periods, i.e. storms occurring during the earlier time period have been concentrated in the west and appear to peak later in summer, while those during the later time period have been concentrated in the east and appear to peak earlier in summer. Regional climatic factors are likely to account for these differences. To make an assumption that there has been an overall shift in the seasonal pattern of storms for the whole time series would be erroneous.

7.4 Time of occurrence of storms

The exact time of occurrence was specified for only 42 of the 179 storms. In all cases, the time of occurrence was taken to the nearest hour. Figure 22 shows the distribution of these 42 storms by time of day.

The graph shows that the majority of the storms occurred in the afternoon and early evening between 14:00 and 19:00, with a distinct peak at 16:00. This can be explained climatologically, as during the earlier part of the day storms develop from convectional heating and usually break late afternoon. This is consistent with Goliger *et al.*'s (1997) study, which finds that most tornadoes in South Africa occur between the same hours. Figure 22 shows that only two storms occurred outside of the expected time period, at 06:00 and 02:00 respectively. The event which occurred at 06:00 was a flash flood in October 1926 in Port Elizabeth and the event at 02:00 was a severe hailstorm which struck farms in the Fort Beaufort area in January 2005. The latter event, in particular, is considered to be most exceptional and occurred with no warning and was accompanied

Figure 22 Distribution of storms by time of day



by no wind – it literally "fell out of the sky in the middle of the night" (Roberts, pers. comm., 2006).

Furthermore, the time of occurrence for a number of storms was described in general terms only, e.g. late afternoon, evening. A total of 35 storms was reported in this way; of these 34 occurred in the afternoon, evening and night and only one in the morning.

From the above analysis it is possible to conclude that for those storms where exact or general times were recorded, most occurred in the afternoon and evening. From this evidence, one might reasonably assume that for those storms which had no record of the time of occurrence, most would have occurred in the afternoon or evening.

7.5 Severe storm type/hazards

Various meteorological hazards of varying intensity were reported during each storm event: tornado, wind, hail, lightning or flash flooding. "Hazard" in this sense refers to the actual *damaging impact* of the hazard and not its potential to cause damage. In the case where no specific mention was made of any particular hazard then the event was described in general terms as a "severe storm".

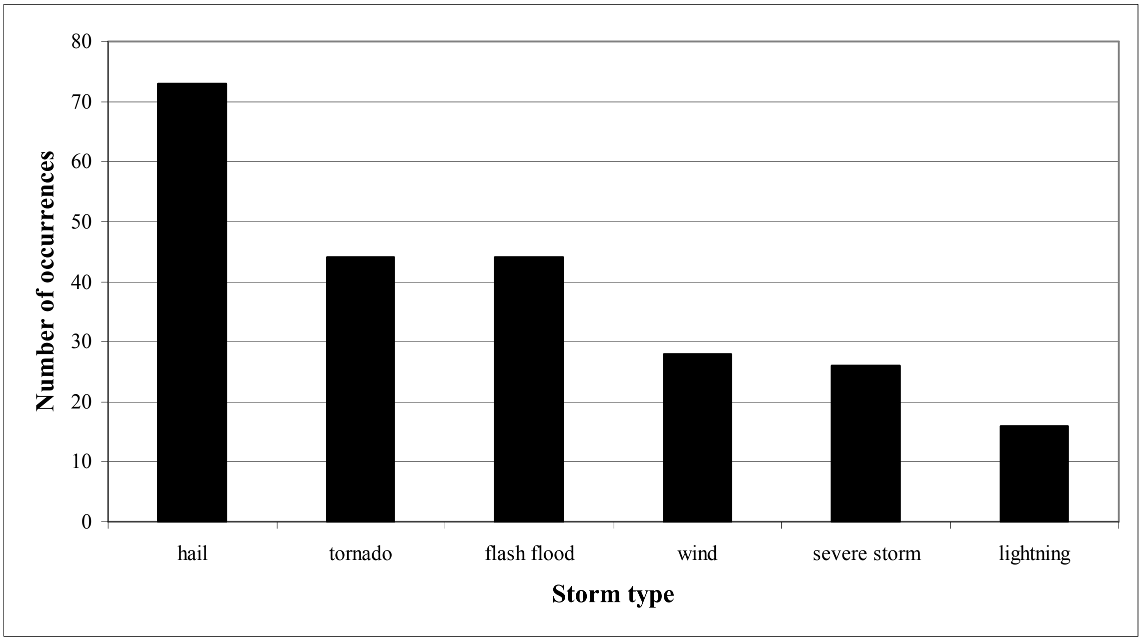
Twenty five percent of the 179 storms were characterised by multiple hazards (where more than one hazard was reported) and 75% by a single hazard, e.g. lightning only. Given the inherent compound nature of severe storms, it is probable that more of the 179 storms did spawn multiple hazards, but that this has not been recorded in the storm reports, as they would most likely have mentioned the single most prominent damaging hazard in each storm. Significantly, lightning occurred as a single hazard in all cases where it was reported, except for one report of lightning and wind. This may be ascribed to the fact that reports of lightning are more likely to be made when there has been resulting death or injury and that no mention would be made of less significant hazards occurring at the time. In addition, lightning strikes are known to be erratic and random and may occur in isolation at some distance from the main severe storm activity where other hazards are present. Analysis also reveals that in many storms hail was reported with tornadoes; this is consistent with Goliger *et al.*'s (1997) study on South African tornadoes. Apart from this, analysis of the data revealed no further particular pattern of combination of hazards.

Figure 23 compares the number of times each hazard (tornado, hail, wind, lightning, flash flooding or general severe storm) was reported in total for the 179 storm events. Hail was the most frequently reported hazard (32%), followed by tornadoes (19%), flash floods (19%), wind (12%) and severe storms (11%). Although all storms by definition were thunderstorms, lightning (7%) was the least frequently reported hazard. The geographic distribution and impact of hail and lightning will be analysed further in the next section.

7.6 Storm severity

Chapter 6 explains the method used to classify/rank the 179 storms according to the severity of recorded impact and damage, on a scale from TS1 (lowest) to TS5 (highest). It is important to note that the differential impact of storms is inextricably linked to the vulnerability of the populations living in the various geographic areas and this must be

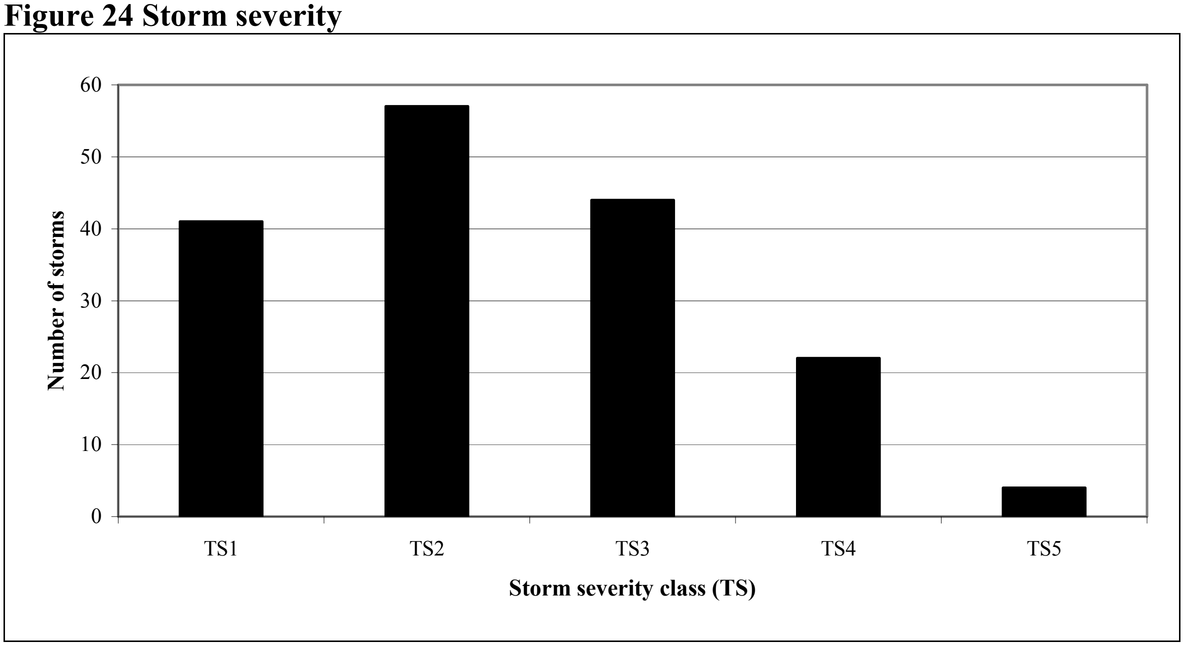
Figure 23 Frequency of storm type



borne in mind throughout the ensuing analysis and discussion. Key vulnerability patterns in the province will be examined in detail in the next chapter.

Figure 24 provides the results of the classification.

Figure 24 Storm severity



The graph exhibits a strongly positively skewed distribution pattern, which is to be expected as a higher frequency of lower impact storms (TS1 and TS2) should naturally occur, compared with a lower frequency of higher impact storms (TS3 to TS5). Storms classified as TS2 (significant) are the most frequent and this confirms the "significant" impact of storms in this category. The lowest category (TS1, moderate) shows evidence of under-reporting as one might normally expect a higher frequency of the lowest impact storms, i.e. the number of naturally occurring TS1 storms should be the highest of all the categories from TS1 to TS 5. Figure 24, however, shows that only 23% of storms were classified as TS1, while 32% were classified as TS2. However, low impact storms are less likely to be reported; this problem has been discussed already in Chapter 3.

When combined, the lower-impact TS1 and TS2 category storms account for 55% of reported storms. The mid-range TS3 (severe) category storms comprise 25% of reported storms, while TS4 (very severe) storms comprise 12% and TS5 (devastating) comprise 2%. Unclassified storms comprise 6%. These frequencies are consistent with the range of anticipated values in a Probability Distribution Function, where the higher impact extreme events become increasingly less frequent (Landman, 2006).

7.6.1 The geographic distribution and frequency of TS1-TS5 category storms

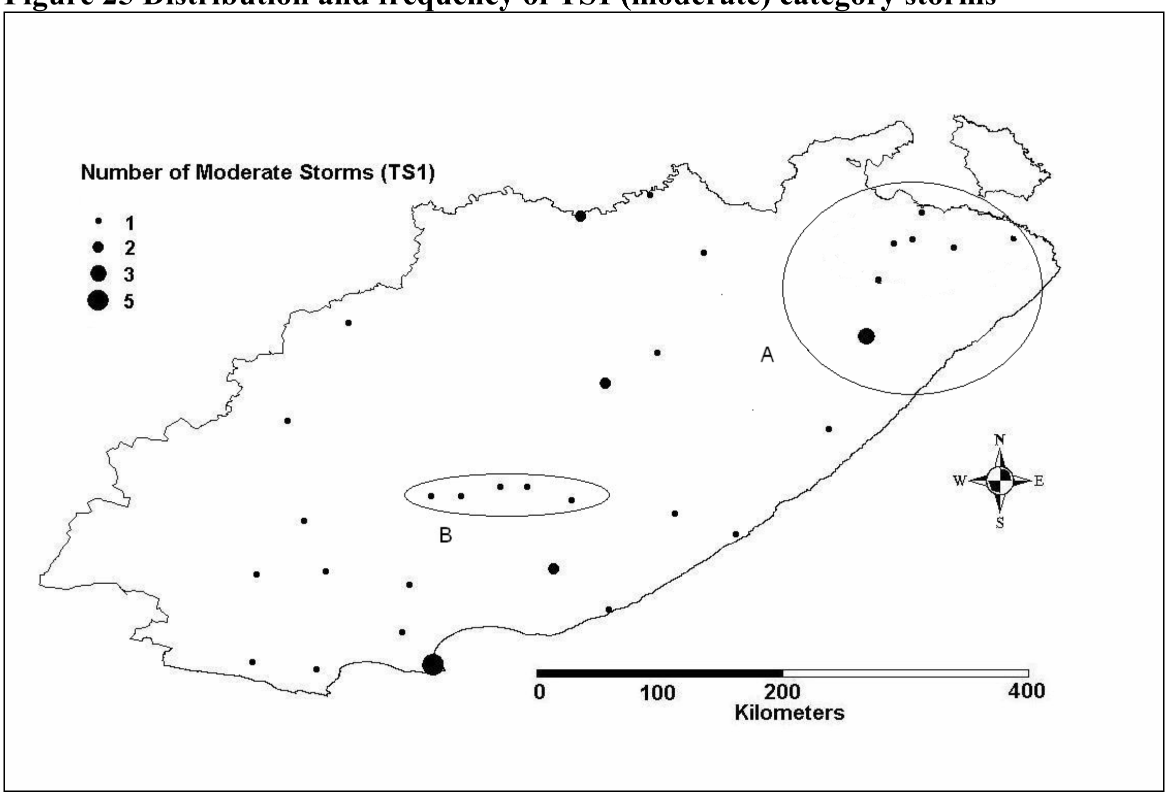
7.6.1.1 TS1 (moderate) category storms

Table 3 shows the impact criteria used in the classification and Figure 25 shows the geographic distribution of TS1 category storms for the time series *(vide* Figure 14 for individual place names). A total of 41 storms occurred in the lowest TS1 category. What is noticeable from the geographic distribution of TS1 storms is the generally sparse distribution in many of the interior rural areas, but particularly in the north-western and extreme western areas of the province. As has been stressed previously, many of the smaller, low impact storms where there has been no injury or death are more likely to be missed, especially where population densities are low. Significant, too, is the low frequency of storms for any particular place; most are single occurrence. Port Elizabeth and Umtata, however, show a higher frequency of reported storms, which can

Table 3 TS1 (moderate) category storm impact criteria

Severity scale	**TS1**
Description	Moderate
Damage / impact	
Loss of life	Nil
Injuries	Nil
Houses / buildings damaged / destroyed	Few (1-5)
Other damage	Moderate
Livestock killed	Some(1-10)
Homeless people	Some (1-20)
Families affected	Some (1-10)
Area affected	Very localised (e.g. a farm/village)
Fujita-Pearson tornado scale	F0
Rand value of damage	Hundreds to low thousands
Descriptors used in reports	Moderate, localised damage

Figure 25 Distribution and frequency of TS1 (moderate) category storms



be explained by better reporting, which is characteristic of densely populated urban areas.

Figure 25 shows that within this generally random distribution pattern, two areas of particular interest and activity are discernible, *viz.* a relatively large area in the extreme north-eastern areas around Umtata, Mount Ayliff and Tabankulu (marked A), and in the south-central area, a distinct line running west-east from Cookhouse-Adelaide-Bedford-Fort Beaufort-Alice (marked B).

7.6.1.2 TS2 (significant) category storms

Table 4 shows the impact criteria used in the classification and Figure 26 shows the geographic distribution of TS2 category storms for the time series *(vide* Figure 14 for individual place names).

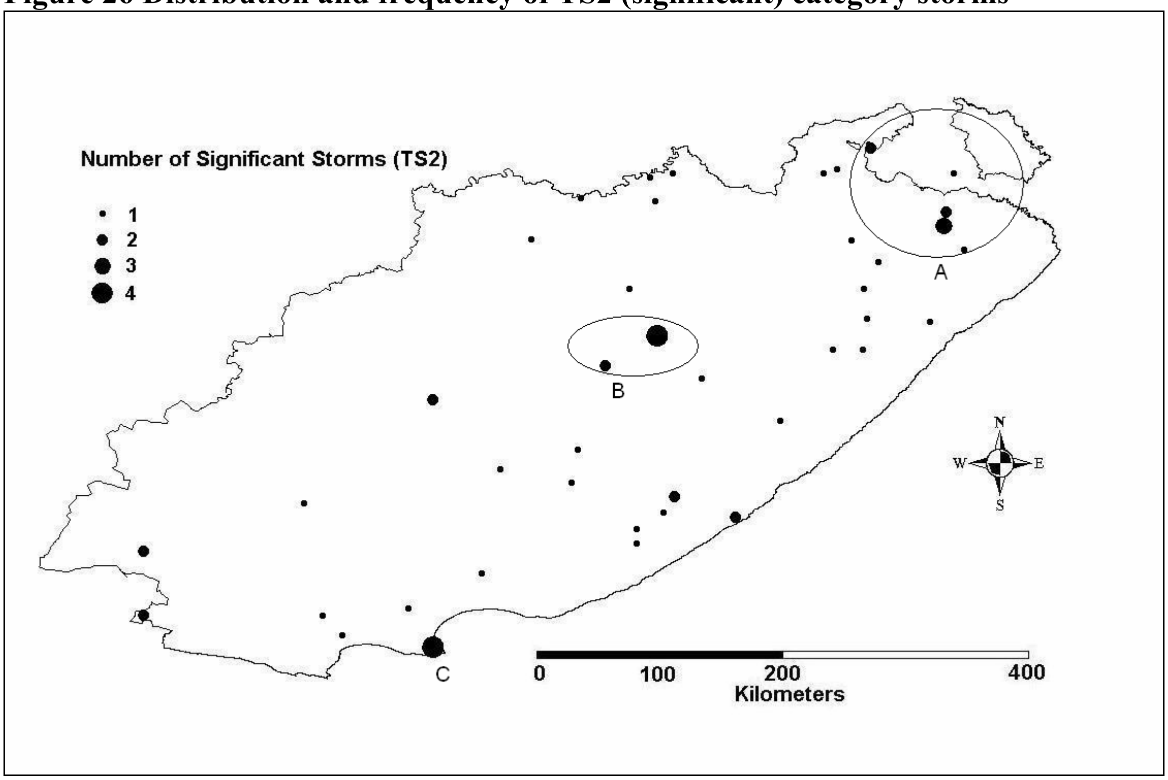
A total of 57 storms occurred in the TS2 category (Figure 26). Table 4 shows that the category ranges in terms of number of houses and buildings destroyed (6-100), number of livestock killed (11-100), and the number of homeless people (21-100) are broader than they are for the corresponding category ranges in the TS1 storms. As such, one might reasonably expect a greater frequency of reported storms within the TS2 category. In addition, where death and injury was reported in the total 179 storms, many were in the low range of 1-3 persons and these are represented in the TS2 category.

The geographic distribution of TS2 storms shown in Figure 26 is similar to that of TS1 storms, but there has been a general shift of storms to the east; storm occurrences in the western and north-western parts of the province are even more sparsely distributed. The far eastern and north-eastern areas show a denser distribution pattern. High storm frequencies are evident in these parts too, in particular at Mount Ayliff, Tabankulu, Kokstad and Matatiele (marked A). The Queenstown-Lady Frere area (marked B) in the central regions displays a secondary high frequency area. The coastal metropolitan region of Port Elizabeth (marked C) also shows a relatively high frequency.

Table 4 TS2 (significant) category storm impact criteria

Severity scale	**TS2**
Description	Significant
Damage/impact	
Loss of life	1 to 2
Injuries	1 to 3
Houses / buildings damaged / destroyed	Many (6-100)
Other damage	Significant
Livestock killed	Many (11-100)
Homeless people	Many (21-100)
Families affected	Many (11-20)
Area affected	Localised (few farms/villages/1 town)
Fujita-Pearson tornado scale	F0/F1
Rand value of damage	Higher thousands
Descriptors used in reports	Destructive, considerable damage

Figure 26 Distribution and frequency of TS2 (significant) category storms



7.6.1.3 TS3 (severe) category storms

Table 5 shows the impact criteria used in the classification of TS3 storms and Figure 27 shows the geographic distribution of TS3 category storms for the time series *(vide* Figure 14 for individual place names).

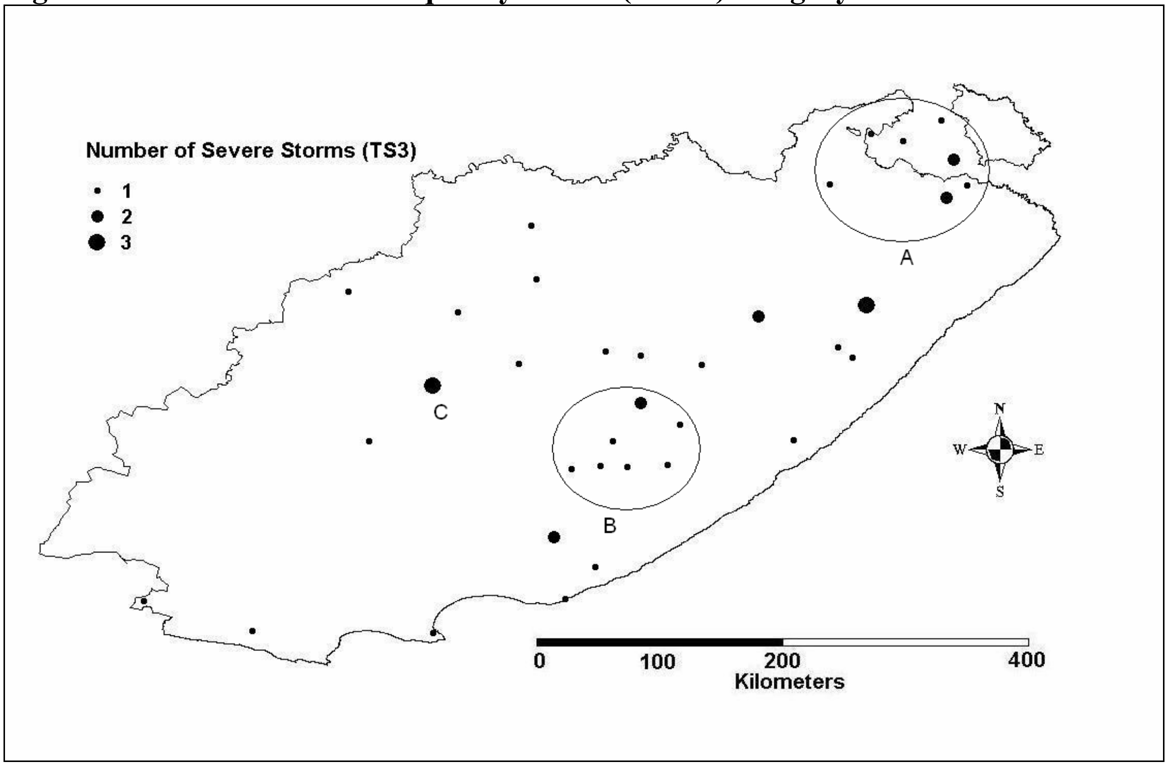
Table 5 TS3 (severe) category storm impact criteria

Severity scale	**TS3**
Description	Severe
Damage/impact	
Loss of life	3 to 5
Injuries	4 to 10
Houses/buildings damaged/destroyed	Lower hundreds
Other damage	Severe
Livestock killed	Lower hundreds
Homeless people	Lower hundreds
Families affected	21-100
Area affected	Wider (more villages/towns)
Fujita-Pearson tornado scale	F1/F2
Rand value of damage	Hundreds of thousands
Descriptors used in reports	Severe/extensive damage, violent

A total of 44 storms occurred in the TS3 category (Figure 27). As shown in Table 5 the impact severity of TS3 storms is increasingly severe with respect to all criteria. In particular loss of life and injury become more significant.

The pattern of storms shows an even greater concentration of storms towards the eastern and north-eastern areas, compared with the distribution of TS1 and TS2 storms. An area of storms is clearly shown in the extreme north-east around Mount Ayliff, Kokstad, Cedarville and Matatiele (marked A). A further area of particular interest and activity is shown in the south-central area (marked B); evident within this area is a line of storms running west-east from Fort Beaufort – Alice – Bisho (King Williams Town). This line is an eastward extension of the line of TS1 storms already identified in Figure 25. Further to the west, and in contrast to the general

Figure 27 Distribution and frequency of TS3 (severe) category storms



eastward trend of storms, is the town of Cradock (marked C), which has experienced three TS3 category storms, all of which produced damaging hail.

7.6.1.4 TS4 (very severe) category storms

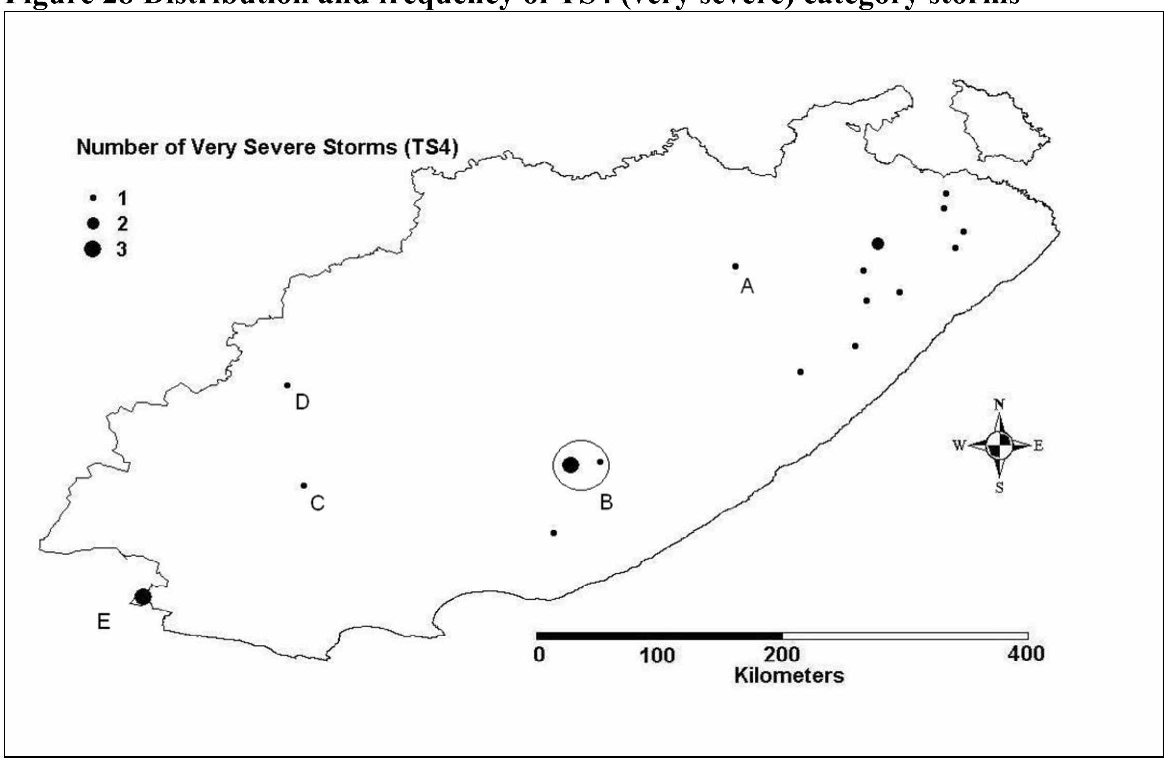
Table 6 shows the impact criteria used in the classification of TS4 storms and Figure 28 shows the geographic distribution of TS4 category storms for the time series *(vide* Figure 14 for individual place names).

A total of 22 storms occurred in the TS4 category (Figure 28). The impact criteria in Table 6 show the extent of very severe damage and loss of life and injury in TS4 storms. Considering the severity of impact, the researcher contends that 22 storms of such impact to have occurred during the time period is very significant. While it is accepted that calculating return periods is problematic when working with an incomplete dataset (Melching and Pilon, 1999), the data indicate that one TS4 category storm should occur in the province on an average once in five years.

Table 6 TS4 (very severe) category storm impact criteria

Severity scale	**TS4**
Description	Very severe
Damage/impact	
Loss of life	6 to 14
Injuries	11 to 50
Houses/buildings damaged/destroyed	Middle hundreds
Other damage*	Very severe
Livestock killed	Middle hundreds
Homeless people	Middle hundreds
Families affected	101 to 200
Area affected	Wider (more villages/towns)
Fujita-Pearson tornado scale	F2/F3
Rand value of damage	Millions
Descriptors used in reports	Very severe damage

Figure 28 Distribution and frequency of TS4 (very severe) category storms



The distribution pattern of TS4 storms (Figure 28) shows an even greater concentration towards the eastern and north-eastern areas of the province. Analysis of the TS4 category storm reports reveals the severe impact of especially hailstorms, tornadoes and lightning occurring singly or in combination in these geographical areas. Lightning, in particular, accounts for a significant proportion of loss of life and injury in TS4 storms in the east and north-east. The pattern of lightning impact will be examined in further detail in the following section. In addition, hailstorms and tornadoes cause severe physical damage to property, crops and infrastructure amongst the poorest and most vulnerable populations of the province (*vide* Figure 52 in Chapter 8). In 1922, 14 workers were killed by extremely large hail in the Qumbu district. Also worth noting in this north-eastern region is a particularly severe hailstorm which occurred recently at the town of Elliot (marked A) in 2006, causing severe damage to property and infrastructure and accounting for millions of Rands in damage. It was described as the worst hailstorm in living memory.

Further to the west, the towns of Fort Beaufort and Alice (marked B) in the south-central area have experienced very damaging TS4 storms. Fort Beaufort, in particular, is worth singling out. The town and surrounding area has suffered from a number of very damaging hailstorms during the time period and in 2000, 2004 and 2005 many citrus farmers in the region experienced millions of Rands in losses from particularly severe hailstorms. Even further west, Jansenville (marked C) and Graaff-Reinet (marked D) have experienced one TS4 storm each (general severe storm and flash flooding respectively). Misgund (marked E), situated in the Langkloof Valley, a valuable deciduous crop growing area, has experienced great losses from very severe storms during the time period: three TS4 storms and a number of lesser category storms, all of which produced damaging hail which devastated the fruit crop. The pattern of hail hazard for the province will be investigated in further detail in this chapter.

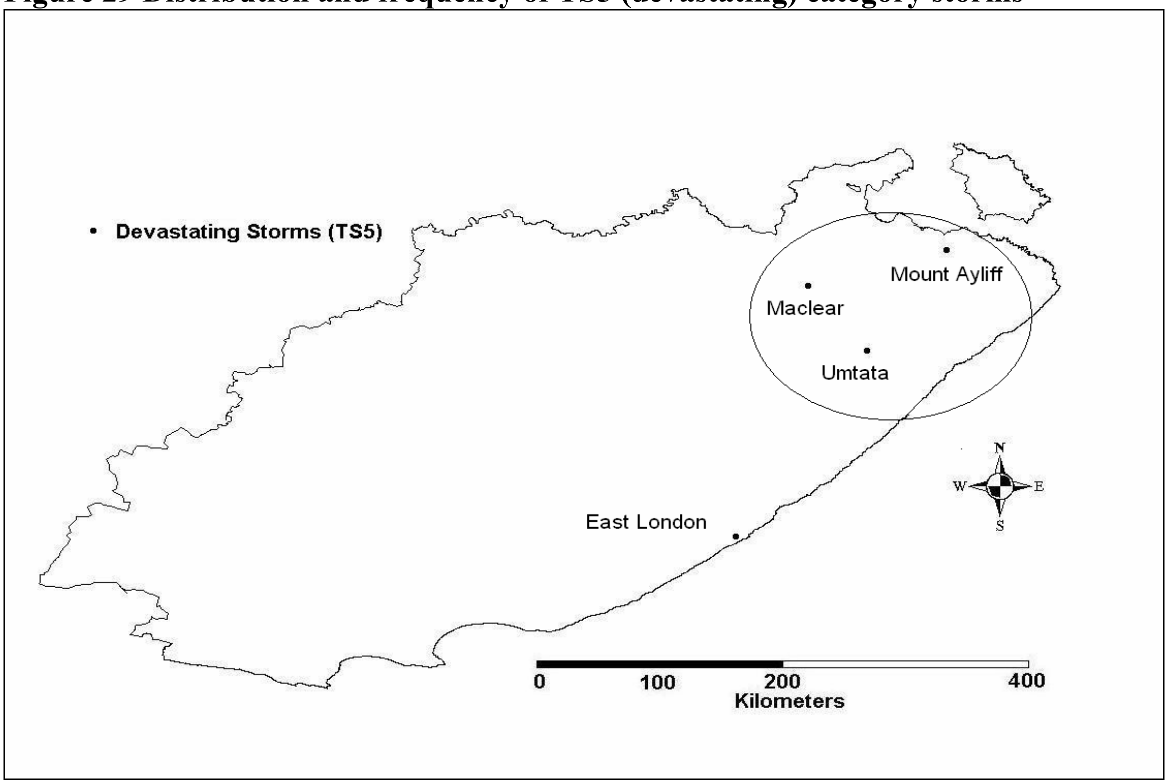
7.6.1.5 TS5 (devastating) category storms

Table 7 shows the impact criteria used in the classification of TS5 storms and Figure 29 the geographic distribution of TS5 category storms for the time series.

Table 7 TS5 (devastating) category storm impact criteria

Severity scale	**TS5**
Description	Devastating
Damage/impact	
Loss of life	15 and more
Injuries	More than 50
Houses/buildings damaged/destroyed	Higher hundreds/thousands
Other damage*	Devastating
Livestock killed	Higher hundreds/thousands
Homeless people	Higher hundreds/thousands
Families affected	More than 200
Area affected	Extensive, disaster area proclaimed
Fujita-Pearson tornado scale	F2/F3/F4
Rand value of damage	Many millions
Descriptors used in reports	Devastating, disaster, incalculable damage

Figure 29 Distribution and frequency of TS5 (devastating) category storms



A total of four storms occurred in the TS5 category (Figure 29). While taking note of the *caveat* concerning the over-emphasis placed on high impact, low frequency events, the researcher is of the opinion that these four events deserve more detailed discussion and analysis, considering their magnitude of impact.

Table 8 compares the main characteristics and impact of the four storms.

Table 8 TS5 category storm comparison

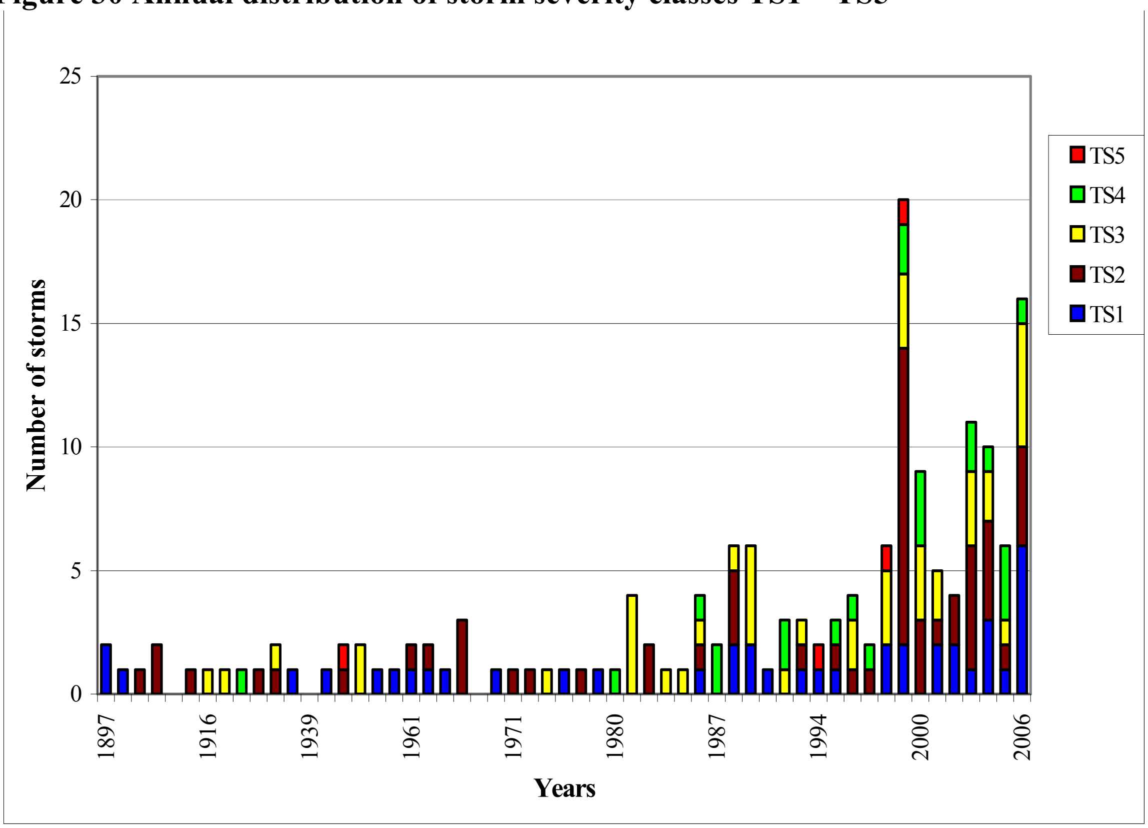
Place	Date	Time	Event	Deaths	Injuries	Other main damage	Rand value
East London	12/04/1953	13:30	F2 tornado		Hundreds	1200 homeless	"Incalculable"
Maclear / Ugie	27/06/1994		Tornado		20	100 houses destroyed, 1600 livestock killed	Not known
Umtata	15/12/1998	14:30	F2 tornado	18	163	1500 buildings damaged	R90 million
Mount Ayliff	18/01/1999	16:30	F4 tornado	21	357	6 villages affected	R3 million

Significantly, all four storms occurred in the eastern and north-eastern areas of the province. In addition, three of the four occurred within a relatively small geographical area in the north-east, *viz.* Maclear/Ugie, Mount Ayliff and Umtata (Figure 29). All four events were reported as tornadoes of varying intensity and interestingly occurred in four different months of the year. The Umtata and Mount Ayliff events occurred during the "hell season" of 1998/1999, where van Niekerk and Sampson (1999) estimate the total economic loss from all storms during the period at R102 million. The East London and Umtata events caused devastating damage to both urban and surrounding rural structures, while the Maclear/Ugie and Mount Ayliff events impacted heavily on primarily rural livelihoods and structures. This urban/rural disparity is reflected in the much higher estimated losses from the Umtata event (R90 million), compared with the relatively low financial losses from the Mount Ayliff event (R3 million), despite the higher number of deaths and injuries. When combined, the Umtata and Mount Ayliff storms account for 39 deaths and 520 injuries, which is significant. Morris (pers. comm., 2006) confirms that the Mount Ayliff area experiences very severe storms (particularly hailstorms, tornadoes and damaging straight-line winds) every year during the mid-summer months, with severe impact on the communities in the surrounding rural villages; in many cases storms are never reported and communities have to recover and repair houses and infrastructure themselves. Morris (pers. comm., 2006) reports that during the 1990s one particularly severe summer season produced nine severe hailstorms, of which three areas caused extensive damage to houses and infrastructure in the Mount Ayliff area. Figure 25 to Figure 29 suggest an increasing severity of impact towards the eastern and north-eastern areas of the province. In general, storms appear to be more frequent and more evenly distributed throughout the province in the lower categories (TS1 and TS2), but become increasingly less frequent but more concentrated in the east and north-east in the higher categories (TS3, TS4 and TS5).

7.6.2 The annual distribution of storm severity

Figure 30 shows the annual distribution of storm severity for the five categories.

Figure 30 Annual distribution of storm severity classes TS1 – TS5



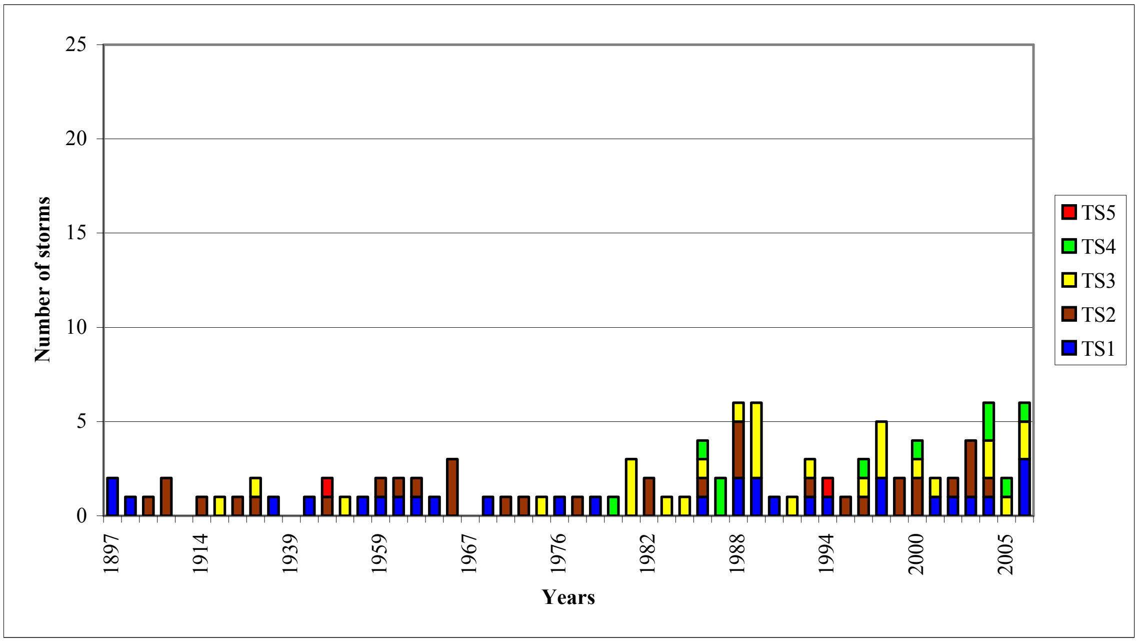
As previously mentioned in this chapter, the marked increase in the number of storms of all categories evident from approximately 1981 is most likely explained by better reporting, especially in the former Ciskei and Transkei in the eastern and north-eastern areas.

Figure 30 shows that the occurrence of TS 1 storms since 1897 is generally evenly distributed for the time series. The relative frequency of occurrence, compared with the other storm categories appears to have remained the same, with some relatively minor deviations. The same may be said of TS2 storms, yet the graph indicates a slight increase in the relative frequency of TS2 storms since 1999. TS3 storms, however, occur less frequently during the earlier part of the time series until 1980. From 1981 onward TS3 storms have been reported more frequently and with greater consistency. Significantly, the higher impact TS4 storms are absent from the record until 1980, with the exception of the hailstorm at Qumbu in 1922. From 1986, however, TS4 storms are reported more regularly. Given that reporting has improved substantially, particularly in the eastern and north-eastern areas of the province, and the assumption that the severity of impact in these areas is likely to be greater due to the high vulnerability of the populations living there, the increase in higher impact TS4 storms is not surprising. Similarly, three of the four TS5 storms have occurred in the vulnerable north-eastern areas since 1994; only one has occurred prior to this at East London in 1953, which has not been a historically disadvantaged area.

The general pattern evident in Figure 30 is one of increasing storm severity and associated impact since 1981. In order to gain a better measure of the effect of increased reporting in the east and north-eastern areas during the later part of the time series, storms of all categories which occurred in the former Ciskei and Transkei areas from 1897 to 2006 were excluded from the database and the annual storm severities were re-calculated.

These results are shown in Figure 31 and serve as a useful comparison with Figure 30.

Figure 31 Annual distribution of storm severity TS1 – TS5 excluding the former Transkei and Ciskei



Essentially Figure 30 and Figure 31 provide a west / east comparison of storm severity for the time period. Figure 31 shows the occurrence of storms for mainly the western areas of the province (excluding the former Transkei and Ciskei), while Figure 30 shows the occurrence of storms for the whole province. The graph for the western areas shows that from 1981 there is a noticeable increase in the annual occurrence of all storm categories, but in particular the higher impact TS3 and TS4 storms; this suggests not only better reporting of storms in general, but also a greater frequency of more damaging storms, in particular hailstorms. This may indicate an increase in the absolute number of severe storms *occurring*, as opposed to being *reported* in the western areas of the province, which may be linked to regional climate change. In addition, a steady urban influx and rapid growth of vulnerable informal settlements surrounding the main urban areas since the 1980s (Berry *et al.,* 2004) may be a factor in increasing the severity of impact of storms. Improved coverage of severe weather events since the advent of television in this country in the mid-1970s may also have played a role in increasing the number of reported storms. However, this increase in the later part of the time series is not as marked as that observed in Figure 30, where the rapid increase in the reporting of storms in the former Transkei and Ciskei areas in the east and north-east accounts for the steep rise in the graph. Whether one can determine with any degree of certainty if the overall increase in storms for the province is related more to changing climate patterns or to better reporting is questionable. Similarly, the high vulnerability of marginalised populations in the eastern areas of the province would play a significant role in increasing the number of higher impact storms being reported; to ascribe this increase to possible climate change would be tenuous.

To conclude, the rapid increase in the number of reported storms shown in Figure 30 can be attributed to both better reporting and the increasing impact on highly vulnerable populations.

7.7 The pattern of injuries and deaths

Figure 32 and Figure 33 show the total number of injuries and deaths reported in the 179 storms for the time series.

Figure 32 Total number of injuries in all storms: 1897 - 2006

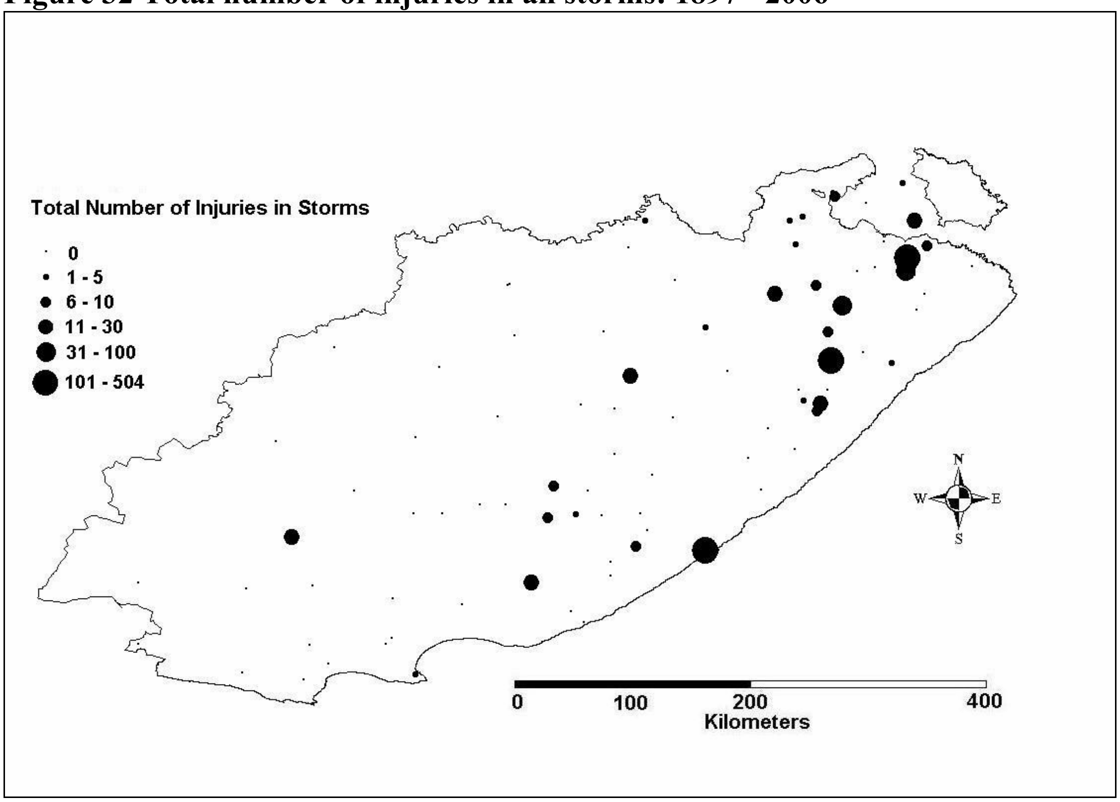
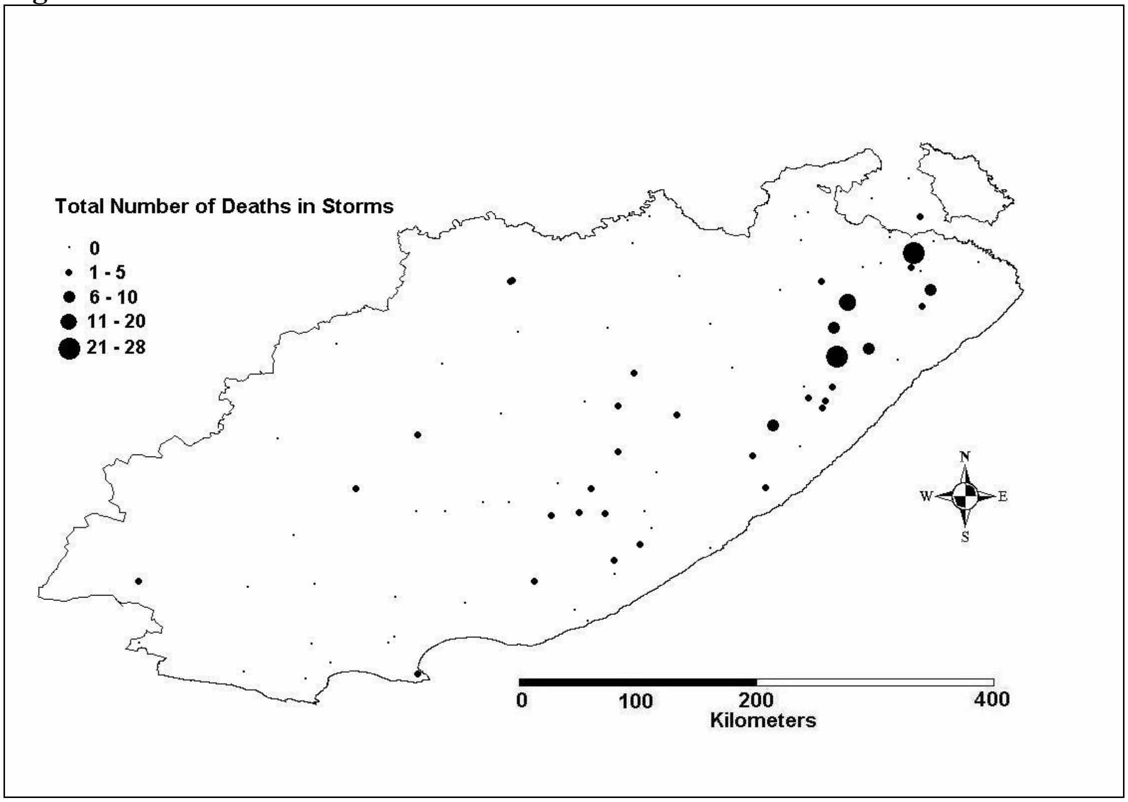


Figure 33 Total number of deaths in all storms: 1897 - 2006



The distribution pattern for total injuries and total deaths shows a significant concentration in the eastern and north-eastern areas of the province. The researcher asserts that this pattern reflects the generally higher storm frequencies/storm severity in the east *combined* with the high vulnerability of the people living there. Injuries and deaths result from damaging winds (which cause houses and buildings to collapse and roofs to be torn off), flying debris (corrugated iron, branches, *etc.*), very large hail, river drownings, and severe lightning strikes (where as many as 12 people have been killed or injured in one event).

Figure 32 and Figure 33 show that a number of storms caused no deaths or injuries; this pattern is distributed fairly evenly throughout the province. It is important to note that Figure 32 and Figure 33 show the accumulated loss of life and injury for a particular place for the time series. Two important patterns emerge. Firstly, a significant number of places have experienced recurring loss of life and injury from numerous storms which have occurred during the time period, e.g. Umtata and surrounds, Tabankulu, Mount

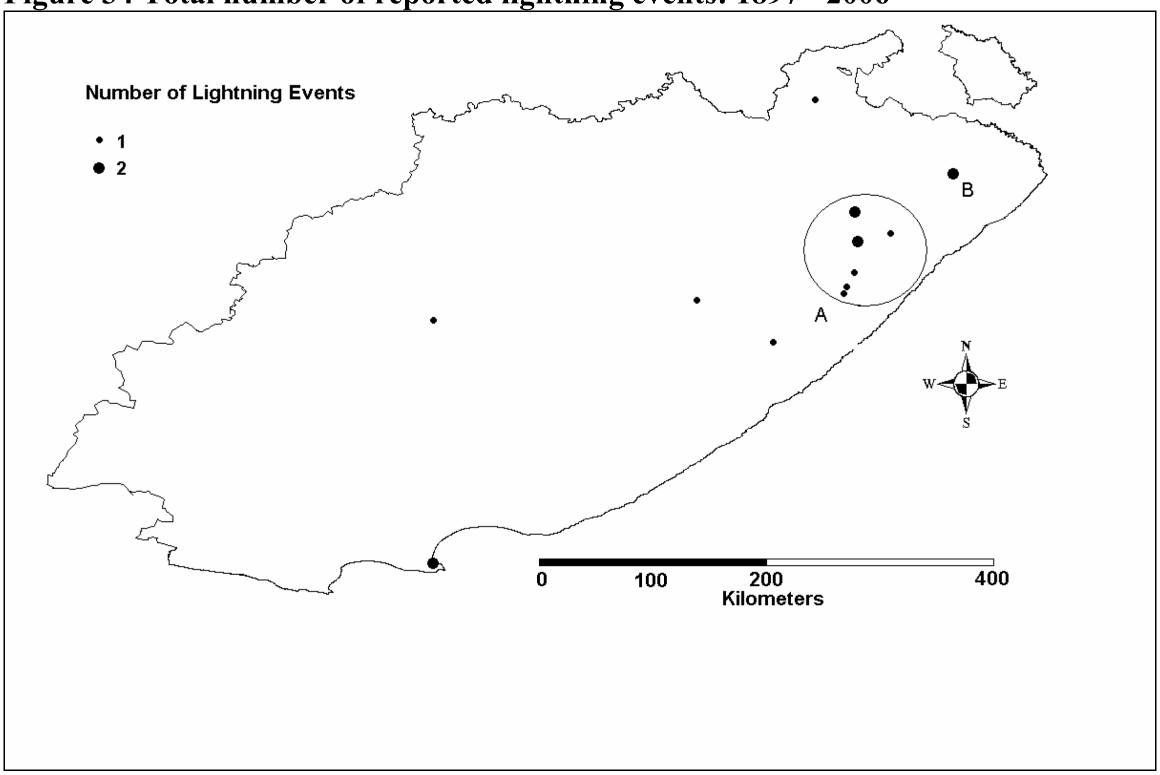
Ayliff and Tsolo *(vide* Figure 14 for individual place names). Within this region, the 1998/1999 season is worth emphasising, where the combined losses from the TS5 category storms in Umtata (1998) and Mount Ayliff (1999) were 39 deaths and 520 injuries.

Secondly, some places have recorded a single storm for the time period which has resulted in high loss of life and injury, e.g. Cathcart (5 drownings in a flash flood); Idutywa (six deaths in a tornado); Flagstaff (eight deaths from a single lightning strike).

7.8 The pattern of lightning hazard

Figure 34 shows the pattern of reported lightning events from 1897 to 2006.

Figure 34 Total number of reported lightning events: 1897 - 2006



A total of 16 lightning events is shown in Figure 34; of these 15 resulted in injury or loss of life; one event caused huts to be burnt to the ground, with no loss of life or injury.

The heavy bias of reported lightning events towards the eastern and north-eastern part of the province is clearly evident. In particular, a clustering of events is noticeable in Umtata and the surrounding rural villages (Mqanduli, Libode, Elliotdale, Tsolo) (marked A in Figure 34, *vide* Figure 14 for individual place names. In the extreme north-east, Flagstaff (marked B) shows as another high frequency and high impact area. Disaster Management officials in Umtata report that the Flagstaff/Lusikisiki area, in particular, is very prone to lightning strikes. They are of the opinion that lightning in this localised area accounts for many more injuries and deaths than reports indicate (Mpiti, pers. comm., 2006). An exception to the general pattern of clustering in the rural north-east is Port Elizabeth, where two lightning incidents have been recorded in 1995 and 2004, causing three deaths in total.

Importantly, lightning events are recorded in the database from only 1992 onwards. There is no valid climatological reason for less lightning occurring before 1992 so one could reasonably assume that the 16 events and associated injury and loss of life represent only a small proportion of the events which have actually occurred since 1897.

Gill (2006) cites research conducted at MEDUNSA (Medical University of South Africa) which reveals that in many cases lightning deaths in South Africa are incorrectly ascribed by medical practitioners who complete death certificates in rural clinics and hospitals to other causes, such as a heart attack. In addition, much superstition surrounds lightning deaths in the rural parts of South Africa and witchcraft is often seen as the cause. According to Xhosa beliefs, people killed by lightning which has been initiated by witchdoctors are buried on the spot (SAWS, 2004b). This may result in many cases not being reported. These two factors will most probably cause a substantial under-representation of the true incidence of lightning deaths and injuries in the Eastern Cape.

Table 9 summarises the impact of recorded lightning events since 1992.

Table 9 Impact of lightning events: 1992 - 2006

Year	Number of people killed	Number of people injured
1992	8	
1995	1	
1997	2	
1999	9	10
2000	3	2
2001	1	
2003	15	25
2004	4	1
2005	4	11
2006	2	1
Total	**49**	**50**

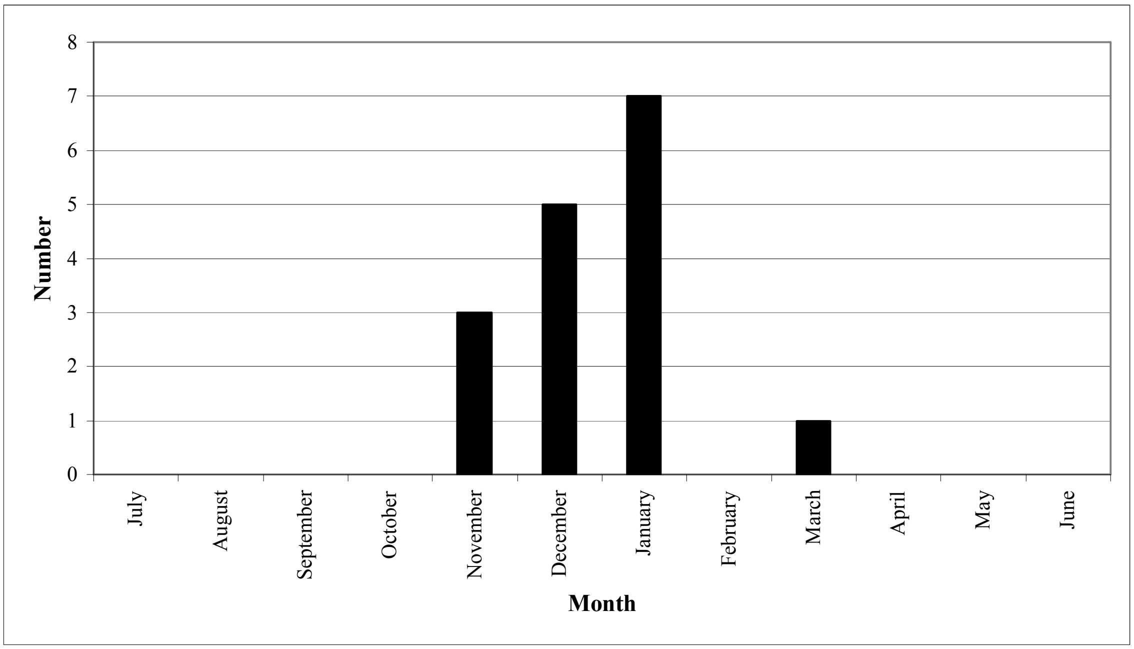
The researcher firmly asserts that a total of 49 deaths and 50 injuries over a period of only 15 years represents a considerable impact on particularly the rural populations of the province. In addition, it can be reasonably assumed that these figures would be substantially higher if all incidents were reported and recorded.

It has been shown in Chapter 3 that the rural areas of the east and north-east experience a higher frequency of lightning strikes in general. Added to this, populations in these areas are more vulnerable to the impact of lightning strikes, for the following reasons. Firstly, dwellings are predominantly of traditional thatch and mud construction (*vide* Figure 46 in the Chapter 8), do not have lightning conductors and are readily combustible. Secondly, dwellings are often located on exposed high-lying areas which are more susceptible to lightning strikes. Thirdly, many rural inhabitants are not aware of the necessary precautions to take in a lightning storm and often seek shelter under trees and other structures which attract lightning (Sampson, pers. comm., 2006).

It is worth mentioning that lightning also causes livestock losses (Painter, pers. comm., 2006) and veld fires, but accurate quantification of these impacts proved impossible due to a lack of records and hence fall outside the scope of this thesis.

The seasonal distribution of the 16 reported lightning occurrences is shown in Figure 35.

Figure 35 Seasonal distribution of lightning events: 1992 - 2006



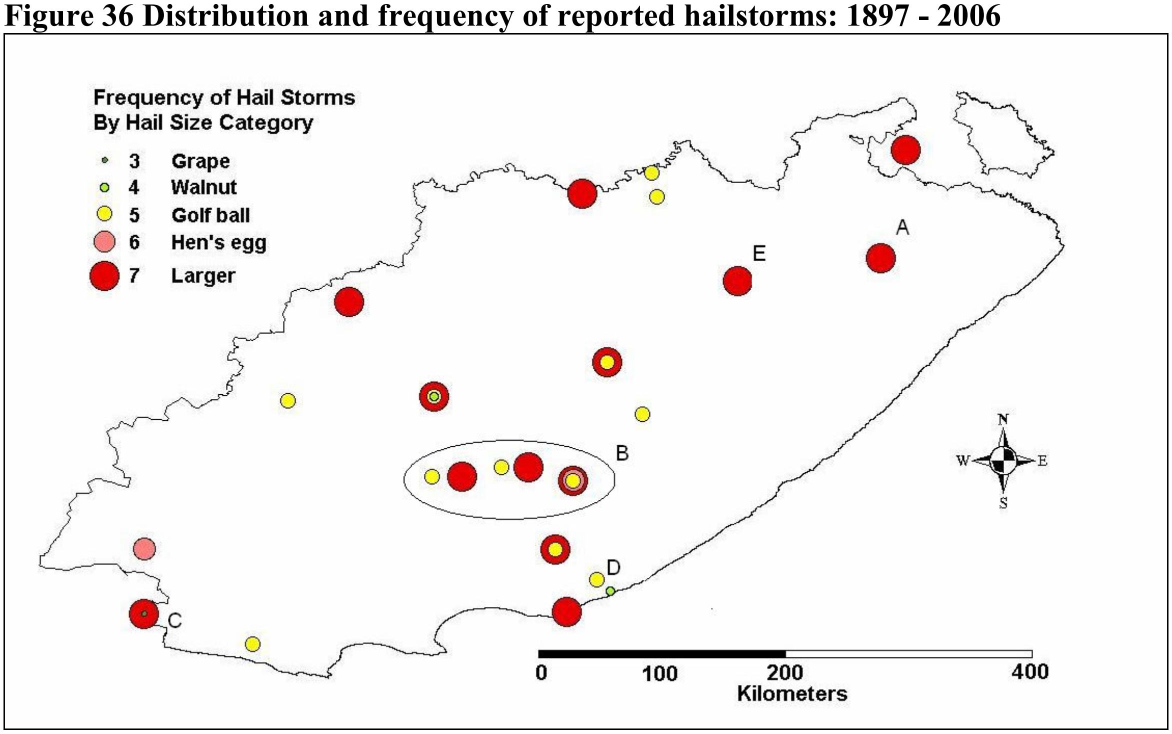
The pattern shown corresponds reasonably well with the seasonal distribution of all storms from 1992-2006, shown in Figure 21 (section 7.3), where November, December and January are also shown as high frequency months. There are important differences between the two graphs, however. Firstly, the highest frequency month for lightning is clearly the single month of January, while the corresponding peak for all storms is shared by December and January. Secondly, while no lightning events have been recorded in February for 1992-2006, the graph for all storms records seven events for the same time period. As such, the lack of lightning events for February is most likely a reporting anomaly. Given the small lightning dataset and the inherent problem of possible unreliability, it would be incorrect to draw too many inferences from the graphed data. Nonetheless, it appears significant that the month of January clearly reflects the highest number of reported lightning events; one may make the tentative assumption that January represents the highest risk month for lightning occurrences for the far eastern parts of the province. Together, late autumn (November) and mid-summer (December-January) show clearly as the highest risk months overall.

7.9 The pattern of hail hazard

Figure 23 (section 7.5) shows that hail is the most frequently reported hazard (32%) in the 179 storms. Difficulties surround the actual quantification of hail damage in each hailstorm as reports often did not specify only hail damage, but damage caused by the storm in general. This is particularly difficult where multiple hazards were reported, e.g. tornado and hail. Furthermore, many reports did not provide an indication of hail size.

Figure 36 shows the distribution pattern and frequency of the 32 storms where hail size was reported. Importantly, it shows only a proportion (44%) of the total number of hailstorms reported. The method used to classify reported hailstorms into hail size categories is outlined in Chapter 6 (section 6.2.2.8).

Figure 36 Distribution and frequency of reported hailstorms: 1897 - 2006



The distribution pattern evident in Figure 36 shows an almost complete absence of storms in the former Ciskei and Transkei in the eastern areas of the province, with the exception of the severe hailstorm in Qumbu (marked A, *vide* Figure 14 for individual place names) in 1922, which claimed the lives of 14 labourers from falling hailstones. The database of all storms from 1897 to 2006 reveals very few storms in the former Ciskei and Transkei where damage was ascribed definitely to hail. Storm reports from these areas often included hail, but in conjunction with other hazards such as wind, tornado, *etc.* In addition, only the storm at Qumbu in the eastern area of the former Transkei and Ciskei provided a clear indication of hail size which could be categorised. As such, it is important to note that Figure 36 shows only those hailstorms where hail size could be categorised accurately from information provided in the reports. The lack of precise hail size reports from the eastern parts of the province accounts for the skewed distribution pattern shown in Figure 36.

The pattern for the remainder of the province shows a reasonably even geographical spread of storms. Whilst hail results in losses to both subsistence and commercial farmers, the database shows that reports are far more frequent from areas which support commercial farming. It is reasonable to assume that hailstorms which result in substantial economic losses to commercial farmers receive prominence in reporting and therefore this accounts for the pattern shown in Figure 36, reflecting a bias towards the central and western areas of the province, which are primarily commercial farming areas. Perry (1995) suggests that the damage potential on modern economic enterprises (which would include commercial farmers) in South Africa has increased and as a result is more frequently noted, compared with the early 1900s. A few areas have been selected for further discussion to provide an indication of the impact of very severe hailstorms on commercial farming in the province. In two of these areas, field research and interviews were conducted with local farmers.

Firstly, a line of hailstorms shows clearly in the Fort Beaufort area (marked B), occurring along the southern edge of the Winterberg Mountains from Somerset East to Fort Beaufort. The commercial citrus farms in the Kat River Valley area near Fort Beaufort have been severely affected by a number of very damaging hailstorms in the past, particularly in the last seven years. Economic losses have run into millions: in 2000 (R5 million); 2004 (R13 million); 2005 (R4 million). Hail size in all three storms was reported as golf ball size and larger. Farmers in the region do not often insure their crops against hail as insurance premiums are very high and increase even further after the first damage claim (Painter, pers. comm., 2006). The extent of damage to crops depends on the age of the crop, where the younger fruit is more susceptible to hail damage. In addition, larger size hail does not always inflict more damage on the fruit than smaller size hail; often smaller hail (grape or walnut size) with sharp irregular edges causes more damage (Painter, pers. comm., 2006).

Secondly, the Misgund area (marked C) in the Langkloof Valley, a productive deciduous farming region in the extreme western part of the province, has suffered regular losses from severe hailstorms: 1964; 1977; 1985 (millions of Rands); 1987 (millions of Rands), 1992 (R750 000); 1996 (R30 million). The 1996 hailstorm produced only marble-size hail and lasted 15 minutes, yet accounted for the worst losses from hail in the area since 1964.

Two other commercial farming areas have reported a single very severe hailstorm for the period 1897-2006, *viz.* Bathurst (marked D) and Elliot (marked E). These two single events are contrasted with the repeated hailstorms experienced in the Fort Beaufort and Misgund areas discussed above.

On the afternoon of 11 April 1995 the pineapple farming area near Bathurst was struck by a severe hailstorm. In a matter of a few minutes four farms had 600 tons of pineapples worth R300 000 totally destroyed by golf ball size hail. In addition a further 9 000 tons of pineapples was partially damaged. The storm cut a narrow swathe of damage a few hundred metres wide and 2.5 km long (Arnold, pers. comm., 2005). All affected farmers were not insured against hail damage as damaging hail occurs very infrequently in the area and is not seen as a risk worth insuring against (Arnold, pers. comm., 2005).

Figure 37 Number of hail events by hail size category 1-7: 1897 - 2006

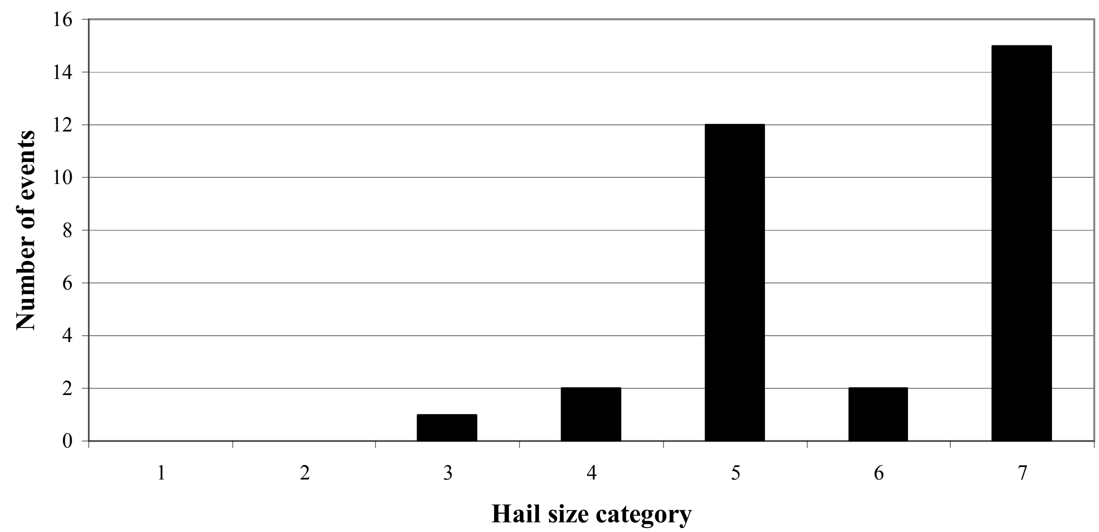


Table 10 Number of hail events by hail size category, size and description: 1897 - 2006

Category	Diameter (mm)	Description	Number of events
1	3	Rice	0
2	6	Pea	0
3	15	Grape, marble	1
4	25	Walnut, dove's egg	2
5	35	Golf ball, pigeon's egg	12
6	50	Hen's egg	2
7	>50	Larger (duck's egg, apple, cricket ball, tennis ball, gem squash)	15
total			**32**

Lastly, the hailstorm which struck the town of Elliot and surrounding farming areas in the north-east on 25 January 2006 warrants further discussion due to the scale of impact. The storm occurred at 19h00, lasted 10 minutes, spawned hailstones the size of a man's fist and was reported as the worst hailstorm in living memory. The following losses were recorded: three injuries, severe damage to houses (39 damaged, 42 destroyed), damage to infrastructure, vehicles and crops. The estimated losses were R12.1 million.

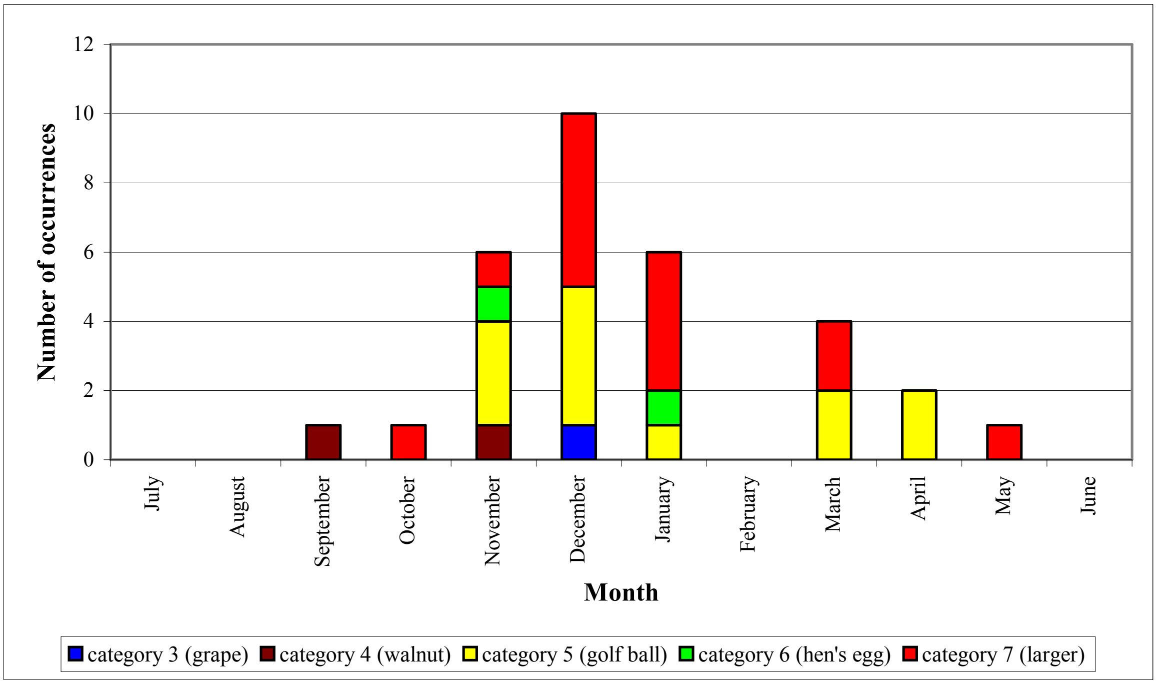
The number of hail events according to the seven hail size categories used by the CSIR (Rae, 2005) in the 32 reported storms is provided in Figure 37 and Table 10.

Figure 37 shows no reported events in the smaller hail size categories 1 and 2. This is not unexpected as hail of rice or pea size is unlikely to cause damage of any consequence and therefore reports of hailstorms where there is little damage are less likely to be made.

The highest number of reported events is seen in categories 5 (golf ball) and 7 (larger). The researcher asserts that this is most likely to be a reflection of affected populations reporting large hail more frequently as opposed to small non-damaging hail. Nonetheless, the fact that 15 reported hailstorms have produced hail larger than 50mm in diameter, with almost invariably devastating impact, is significant. The anomaly evident in the very low number of events reported in category 6 (hen's egg) can be best explained by the likelihood that most people would not normally describe large hail size in terms of a hen's egg but more likely in terms of more commonly used descriptors such as golf ball, apple or cricket ball. As such, given the likelihood of some degree of reporting error around exact hail size, incidences of hen's egg size hail (50mm) are most probably contained in the surrounding categories 5 and 7.

Figure 38 provides an indication of the seasonal distribution of events according to the five reported hail sizes from category 3 to category 7. It further clearly shows that the peak season for all hail size categories is from November to January, with December exhibiting the highest number of events. This pattern corresponds well with the seasonal distribution of all storm types from 1897-2006 shown in Figure 20. Significantly, Figure 38 indicates that the highest risk months for the largest hail are December and January. The lack of hail events for February is anomalous and is most likely due to reporting error, rather than to any real absence of storms for any climatological reason during the month. This anomaly was also seen in the seasonal pattern of lightning occurrences. Given that hailstorms are still reported in March, following the high frequency month of January, it is reasonable to assume that February should be showing at least an equal number of hailstorms as March.

Figure 38 Seasonal distribution of hail size categories 3-7



Studies by the CSIR (Rae, 2005) and Perry (1995) on hailstorms in South Africa reveal similar seasonal distribution and hail size patterns as those shown in this study, yet there are differences worth noting. Perry (1995) compared hail sizes in South African hailstorms reported in CAELUM from 1900-1993 with the TORRO hail size categories used in the UK and found that reports of hen's egg, small peach, billiard ball size hail (46-60mm) and large peach, goose's egg, tennis ball size hail (61-80mm) occurred most frequently; these finding correspond well with the results shown in Figure 37. On the other hand, the CSIR study on hailstorms for the Gauteng Province for the period 1984-1995 was conducted differently as reports on hail sizes were solicited from individual people in the province, who returned 12 365 hail cards representing 658 hail days (Rae, 2005). The results of the study showed that category 2 (pea) and 3 (grape) size hail was by far the most frequently reported. Only 5% of reports were found in larger hail size categories 5-7. These findings would be consistent with a statistical "normal distribution" of hail size categories, which is completely opposite to the findings in this study. This difference may be explained by the fact that the CSIR study solicited reports of all hail sizes from respondents while this study and Perry's (1995) study relied on data primarily obtained from secondary sources such as newspapers, *etc.* which, as mentioned previously, would have a heavy reporting bias towards large size hail events.

An analysis of the reported hailstorms according to hail size category for the period 1897-2006 revealed no identifiable trend in respect of increasing or decreasing incidence of large hail events (categories 5-7). Furthermore, there was no suggestion from the analysis that hail size in reported storms is becoming larger or in fact smaller with time.

7.10 Summary

It must be emphasised that the researcher recognises that in many cases newspaper reports of storms will be biased by vulnerability and that this will affect the analysis provided in this chapter. Whilst recognising this limitation and other problems related to incomplete datasets, the researcher asserts that the analysis presented in this chapter does provide a realistic indication of the spatial and temporal characteristics of severe storm hazard in the province.

CHAPTER EIGHT: THE ANALYSIS OF VULNERABILITY

> *The snake hides itself in a black cloud. If it gets angry it will come down and cause great damage*.
>
> Jackson Msetu, resident of Laer Blinkwater village near Fort Beaufort, October 2001

8.1 Introduction

The physical dimensions of severe storm hazard were analysed in Chapter 7. The aim of this chapter is to examine the broad pattern of vulnerability of the various geographic populations in the Eastern Cape to the impact of severe storm hazard. Using data primarily obtained from the 2001 Census and from *SA Explorer* (2005), GIS-generated maps are presented and analysed in order to determine the pattern of vulnerability for the province.

The ISDR (cited in Wisner *et al.,* 2004; 327) provides an expanded description of vulnerability, which is useful in contextualising the ensuing discussion in this chapter.

"Vulnerability…describes the degree to which a socio-economic system or physical assets are either susceptible or resilient to the impact of natural hazards. It is determined by a combination of several factors including awareness of hazards, the condition of human settlements and infrastructure, public policy and administration, the wealth of a given society and organized abilities in all fields of disaster and risk management. The specific dimensions of social, economic and political vulnerability are also related to inequalities, to gender relations, economic patterns, and ethnic or racial divisions".

8.2 Selection of vulnerability indicators

It is important that vulnerability is contextualised within the specific situation of severe storms in the Eastern Cape. It has been pointed out in Chapter 5 that a very broad range of vulnerability indicators is available in the literature and has been used in various empirical studies, yet not all are relevant to this study. Vulnerability indicators which are *directly* relevant to the local study context and the particular hazard should be selected (UNDP, 2004; Brooks, 2003). Importantly, too, not all the indicators according to the above definition are readily obtainable and/or quantifiable for the Eastern Cape, for example, those related to public policy and administration. After careful consideration of obtainable/quantifiable socio-economic and physical indicators, only certain factors were identified as important and pertinent to this study and were subsequently selected for further analysis. Field research was conducted in areas of the province believed to be highly vulnerable in order to ground-truth certain assumptions made. Further details regarding the ground-truthing process and the rationale and method used for selecting the individual indicators are explained in Chapter 6. To recapitulate, 11 vulnerability indicators were selected and these will be analysed and discussed in this chapter with reference to the local context in the Eastern Cape, at both municipal and district level:

1. Socio-economic indicators
   - Population density
   - Education and income levels
   - Age-sex profile
     - number of children and old people
     - female/male ratio

2. Physical indicators
   - Infrastructure
     - type of dwelling (traditional houses, shacks)
     - road density
   - Access to communications/early warning capacity (telephone, radio, television)

An indication of multiple or composite vulnerability for each municipality was obtained firstly by aggregating the respective values of the 11 indicators for each municipality and, secondly, by calculating an average of these 11 values to derive a "vulnerability index" for each municipality. Five vulnerability categories were subsequently defined, based on the derived indices, *viz.* low, moderate, high, very high and extremely high vulnerability. The method used to derive the vulnerability indices and categories is explained in Chapter 6.

8.3 The Eastern Cape Province: background on demographics and socio-economic indicators

The information in the following two paragraphs is based on data obtained from Statistics South Africa (2003), based on the 2001 Census, and from Qaba and Mafela (1998).

The Eastern Cape Province comprises a land area of 169 580 km^2, making it the second largest province in South Africa. According to the 2001 count, 6 436 763 people inhabit the province, which comprises 14.4% of South Africa's total. This translates to an average population density of 38 persons/km^2, with a broad range from two persons/km^2 to 497 persons/km^2. Black Africans comprise 87.5%, Coloureds 7.4%, Whites 4.7% and Indian/Asian 0.3%. Approximately 65% of the people live in non-urban areas; most of these are young African children, women and older people living in the former Ciskei and Transkei areas.

Key socio-economic indicators based on the 2001 Census show that the province compares poorly with the other eight provinces and with national averages:

- 22.8% of the population aged 20 and above in the Eastern Cape has no education, compared with the national average of 17.9%. Importantly, the level of education is generally lower in rural areas.
- the Eastern Cape has the highest unemployment rate in South Africa at 54.6% compared with the national average of 41.6%. Income-generating or employment opportunities are limited or even non-existent in the rural areas; as such, householders are most likely to be involved in subsistence agriculture, exchange of goods and services and gathering of fuel.

According to Statistics South Africa (2002), the Human Development Index (HDI) measures three indicators of human development: longevity, knowledge and a decent standard of living. Variables measured are life expectancy, educational attainment and real GDP per capita. The HDI ranges from 0 (very low level of development) to 1 (very high level). According to 1996 estimates, the Eastern Cape ranked 7^{th} lowest of the nine provinces at 0.643 against a national average of 0.688. Qaba and Mafela (1998; 53) conclude their report on living conditions in the Eastern Cape in the following way: "…the province is, in many ways, more disadvantaged compared with the rest of South Africa…vast inequalities exist in the Eastern Cape."

A study conducted by Statistics South Africa in 2001 identified 13 rural nodal areas of extreme poverty with a serious lack of facilities in South Africa. Significantly, four of these 13 areas fell within the Eastern Cape, *viz.* the eastern district municipalities of OR Tambo, Alfred Nzo, Chris Hani and Ukhahlamba. A summary of living conditions in the report highlights these four areas as being among the poorest and most deprived of all 13 nodal areas (Statistics South Africa, 2002). As an example, Table 11 provides an indication of the exceptionally poor level of health services in these districts, *i.e.* the extremely low percentage of people with reasonable access to a clinic or hospital. In particular, OR Tambo District and Alfred Nzo District show very low percentages in both categories, compared with national averages.

Table 11 Access to clinics and hospitals

Percentage of people within 14 minutes of the nearest clinic or hospital		
District Municipality	**Clinic**	**Hospital**
OR Tambo	8.1%	1.5%
Alfred Nzo	8.1%	2.1%
Chris Hani	30.7%	5.5%
Ukhahlamba	17.2%	5.4%
National	**36.3%**	**14.3%**

Source: Statistics South Africa, 2002; 1.20-1.23

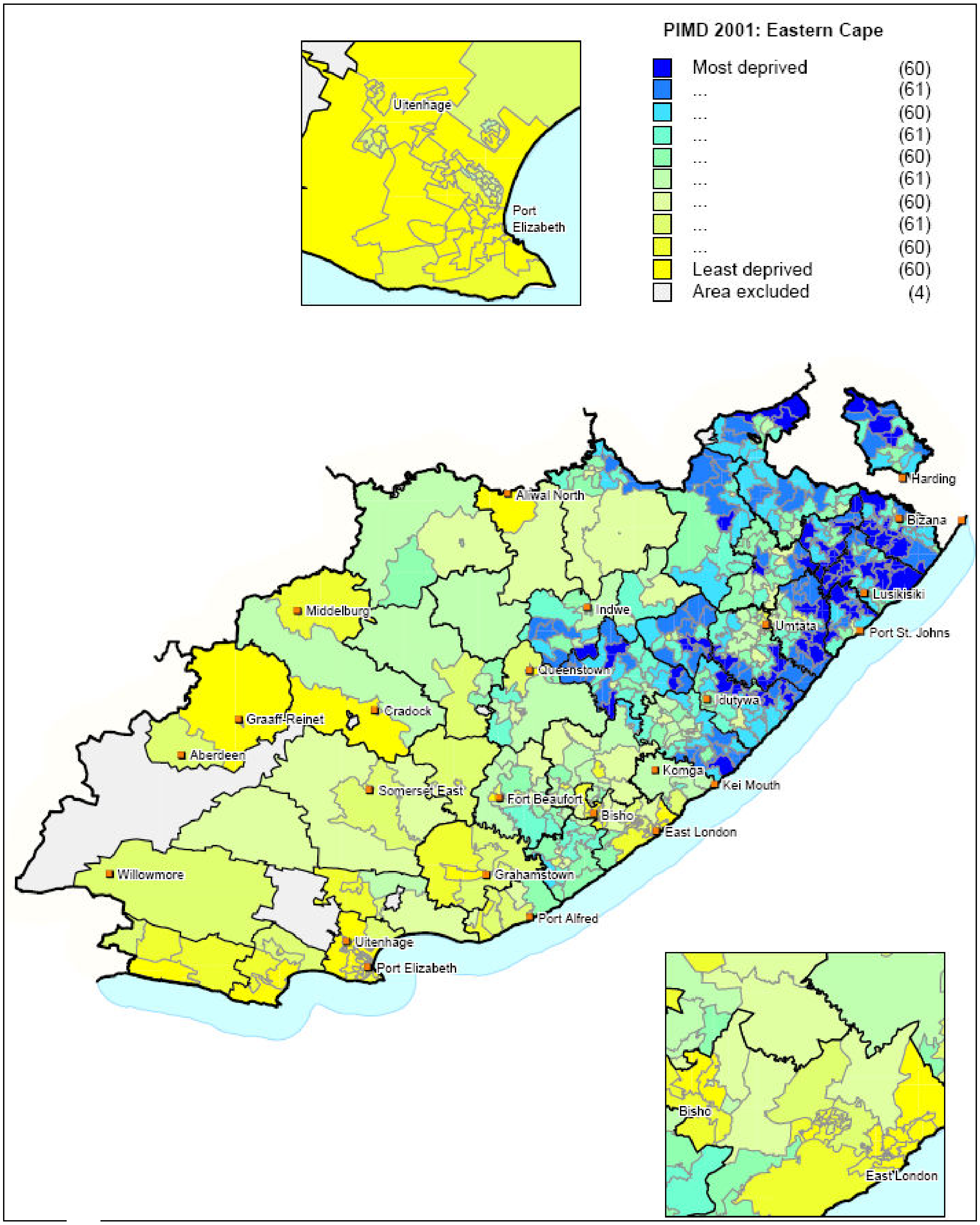
Marked regional and local socio-economic variations exist in the Eastern Cape. A joint report by the University of Oxford, the HSRC and Statistics South Africa (Noble *et al.*, 2006) on the provincial indices of multiple socio-economic deprivation in South Africa highlights distinct variations at ward, municipal and district level. Factors considered in the measurement of multiple deprivation were income, employment, health, education and living environment, based on 2001 census data. Figure 39 shows the results of the analysis for the Eastern Cape; most deprived areas are concentrated in the eastern and north-eastern districts of the province. Local variations at ward and municipal level are pronounced too. Whilst the study by Noble *et al.* (2006) provides a general indication of socio-economic deprivation in the Eastern Cape, it does not focus specifically on vulnerability *per se.* It will be shown, however, in this chapter that the pattern of general deprivation shown in Figure 39 is similar to the pattern of vulnerability to severe storms specifically (Figure 52).

8.4 Vulnerability patterns in the Eastern Cape

The aim of the following section is to provide a broad indication of the vulnerability of various geographic populations to severe storms, at a municipal and district scale. The distinction between a municipality and a district and its applicability to this study has already been made in Chapter 6 (section 6.2.3.2). Figure 40 shows the location of the 38 local municipalities, the Nelson Mandela Metro and six district municipalities in the Eastern Cape and will be referred to throughout Chapters 8 and 9.

Whilst local variations will occur at ward level, it is not the intention to discuss small-scale variations in this thesis. Using data obtained from Statistics South Africa (2006) (based on the 2001 Census) and *SA Explorer* (2005), maps showing the above-mentioned socio-economic and physical indicators were generated using a GIS. Calculations are at municipal level for all indicators. Some indicators are at the individual level, while others are at the household level; these were chosen according to how best each indicator may be expressed and according to the availability of census data formats. According to Statistics South Africa (2003; vi), a household in the South African context is defined as "a group of persons who live together, and provide themselves jointly with food and/or other essentials for living, or as a single person who lives alone".

Figure 39 Eastern Cape index of multiple socio-economic deprivation 2001 at ward level



Noble *et al.,* 2006

Figure 40 Local and district municipalities of the Eastern Cape

It was decided to exclude certain small areas from the analysis, in particular game reserves, which produce anomalous demographic results (Noble *et al.,* 2006). These small areas are shown as blank in all vulnerability maps in this chapter and in the risk maps in Chapter 9.

8.4.1 Socio-economic indicators

8.4.1.1 Population density

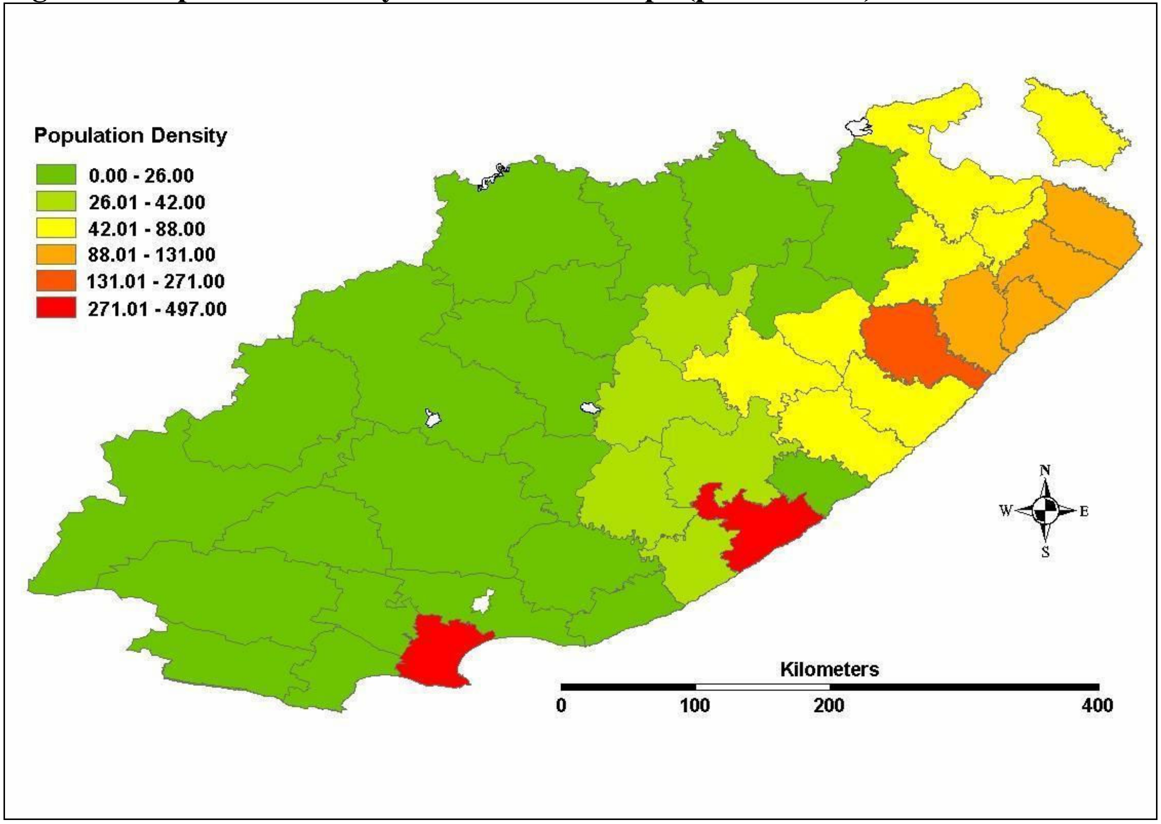
Population density provides an indication of the number of persons per unit area (persons/km^2). Figure 41 provides the pattern of population density for the Eastern Cape. Population densities are clearly shown to be highest (up to 497 persons/km^2) in the large urban areas of the Nelson Mandela Metro and the Buffalo City municipality (East London and surrounding settlements). In addition, Umtata and the surrounding densely populated rural municipalities of King Sabata Dalindyebo, Nyandeni, Port St Johns, *etc.* shows as a secondary high density area in the east (88-271 persons/km^2). Excluding the two coastal metropoles, population density generally increases markedly from west to east. In particular, the far eastern and north-eastern rural areas show dense concentrations of people.

Higher population densities are assumed to be associated with higher vulnerability to storm impacts.

8.4.1.2 Education and income level

Level of education is expressed as the percentage of the population with no schooling (Figure 42), while the level of income is expressed as the percentage of households earning equal to or less than R6 000 per annum (R500 per month) (Figure 43). A general pattern of increasing percentage of people with no education from west to east is observed; similarly, much higher percentages of households earn less than or equal to R6 000 per annum in the eastern areas, which indicates high levels of extreme poverty. The municipalities of Umzimvubu and Umzimkulu show as anomalies in the extreme north-east in respect of a lower percentage of the population with no schooling, compared with the surrounding areas (Figure 42). The researcher suggests that this anomalous

Figure 41 Population density in the Eastern Cape (persons/km^2)



pattern may be a result of a comparatively higher percentage of the population in these two municipalities having one or two years of formal elementary education, but not at more senior level.

Low levels of education and high levels of poverty are believed to be strong indicators of high vulnerability. Not only do they reflect pre-existing deprived living conditions, but they also provide an indication of a community's inability to recover from the impact of a severe storm without some form of external assistance. Compared with wealthier communities, which have the advantages of insurance and reserves, the poorest communities often incur absolute losses and have very little wherewithal to recover (Lewis, 1999). To aggravate matters, a person with no school education will be disadvantaged in terms any scientific understanding of severe storms; this is not to negate the importance of traditional knowledge and understanding of storms but such perceptions are often distorted by the supernatural and witchcraft in the Eastern Cape (Mgquba, 1999; SAWS, 2004b). Furthermore, poor education levels will hinder

Figure 42 Percentage of population with no schooling in the Eastern Cape

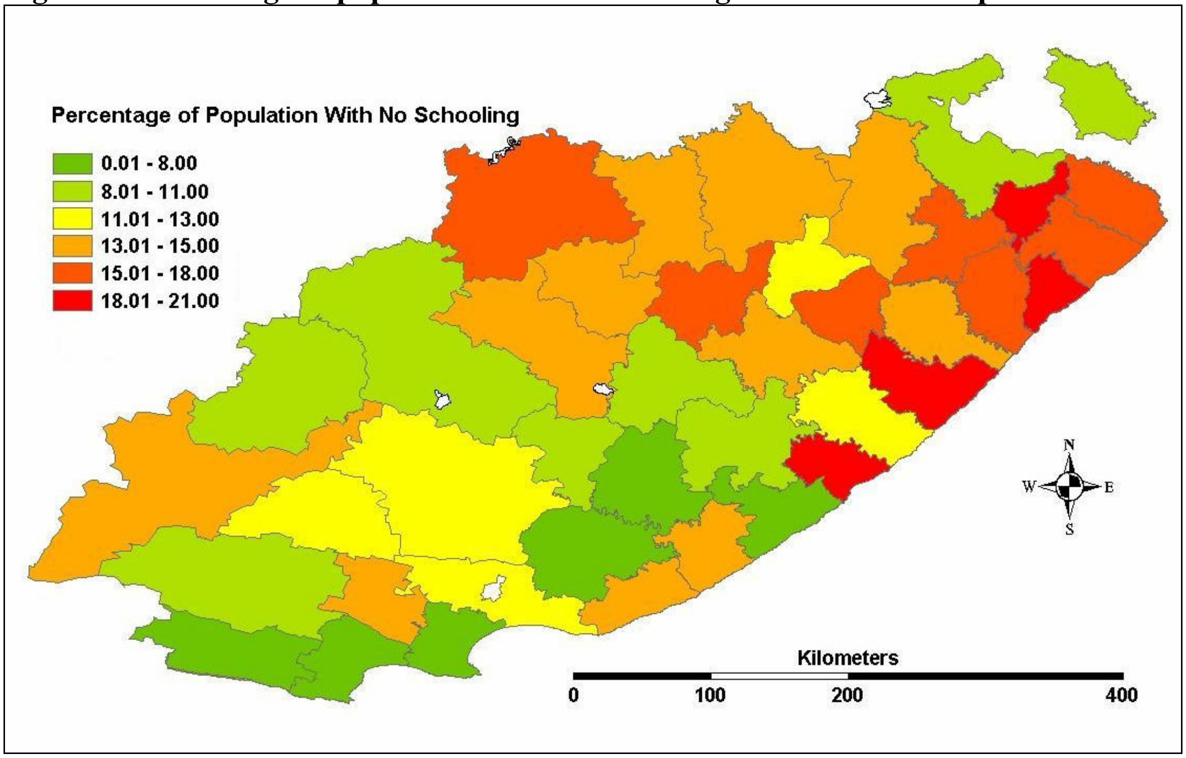
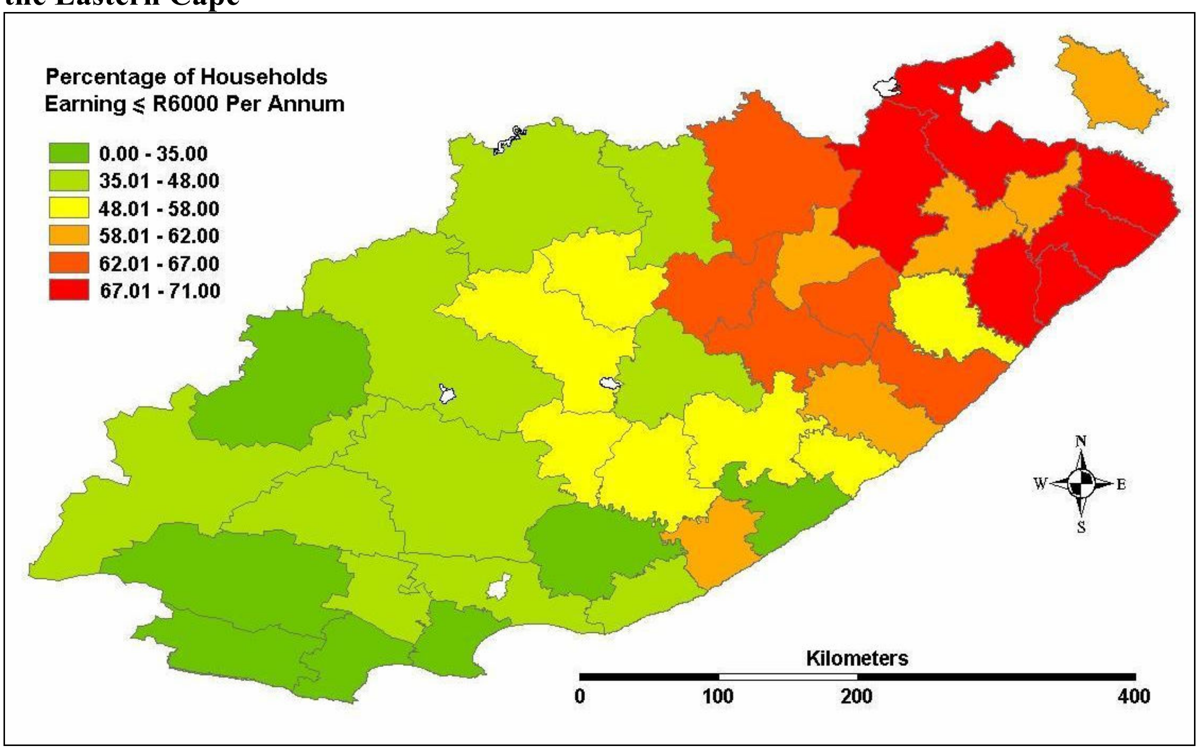


Figure 43 Percentage of households earning equal or less than R6 000 per annum in the Eastern Cape

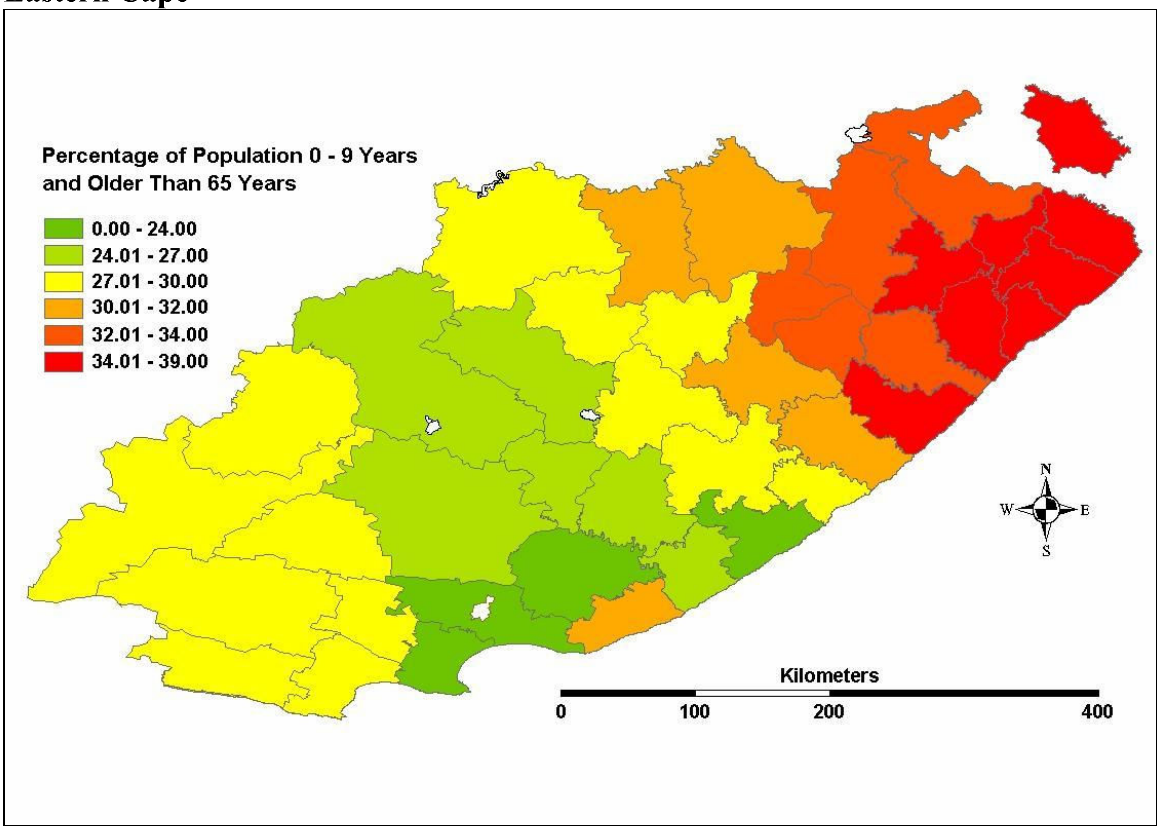


understanding and responding to forecasts and early warnings issued by television and radio.

8.4.1.3 Age-sex profile

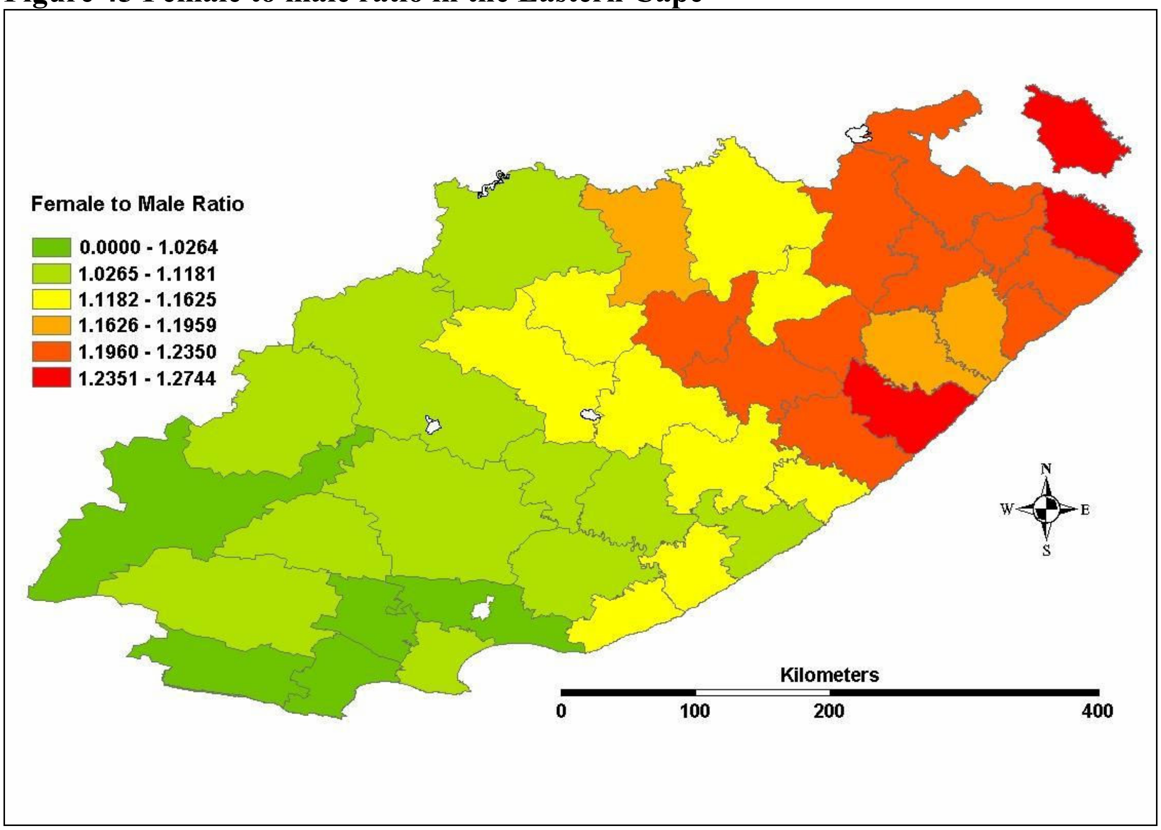
The first age-sex indicator expresses the combined percentage of the population aged 0-9 years (children) and older than 65 years old (old aged). These two age groups have been chosen as they represent the ages at which people are likely to be more vulnerable to severe storm impacts. Figure 44 clearly shows the high percentages of these two age groups concentrated in the extreme north-eastern areas of the province.

Figure 44 Percentage of the population 0-9 years and older than 65 years in the Eastern Cape



The second indicator expresses the female/male ratio for the province. Figure 45 indicates the predominance of women in the eastern areas of the province. While some debate surrounds the assumption that females are more vulnerable to the impact of natural hazards in general, the researcher asserts that in the rural areas of the Eastern Cape where women predominate, communities will be more vulnerable in the impact of severe storms. In the aftermath of a storm, women will have to divide their efforts between the routine household duties of cooking, cleaning and child-minding and the additional burden of salvaging and protecting of homes and household goods, followed by the repair and rebuilding of their homes. It is contended that in areas with equal female/male ratios, more men would be able to attend to the strenuous and physical tasks of clearing storm debris and home rebuilding, *etc.* thereby reducing the overall vulnerability of communities.

Figure 45 Female to male ratio in the Eastern Cape



8.4.2 Physical/infrastructural indicators

8.4.2.1 Type of dwelling

Two indicators were selected, *viz.* traditional houses and shacks. It is contended that both types of houses are more vulnerable to the impact of severe storms, compared with conventional brick and mortar houses. Fieldwork and interviews with inhabitants conducted by the researcher in high impact areas of the province confirms this

Figure 46 Percentage of households living in traditional houses in the Eastern Cape

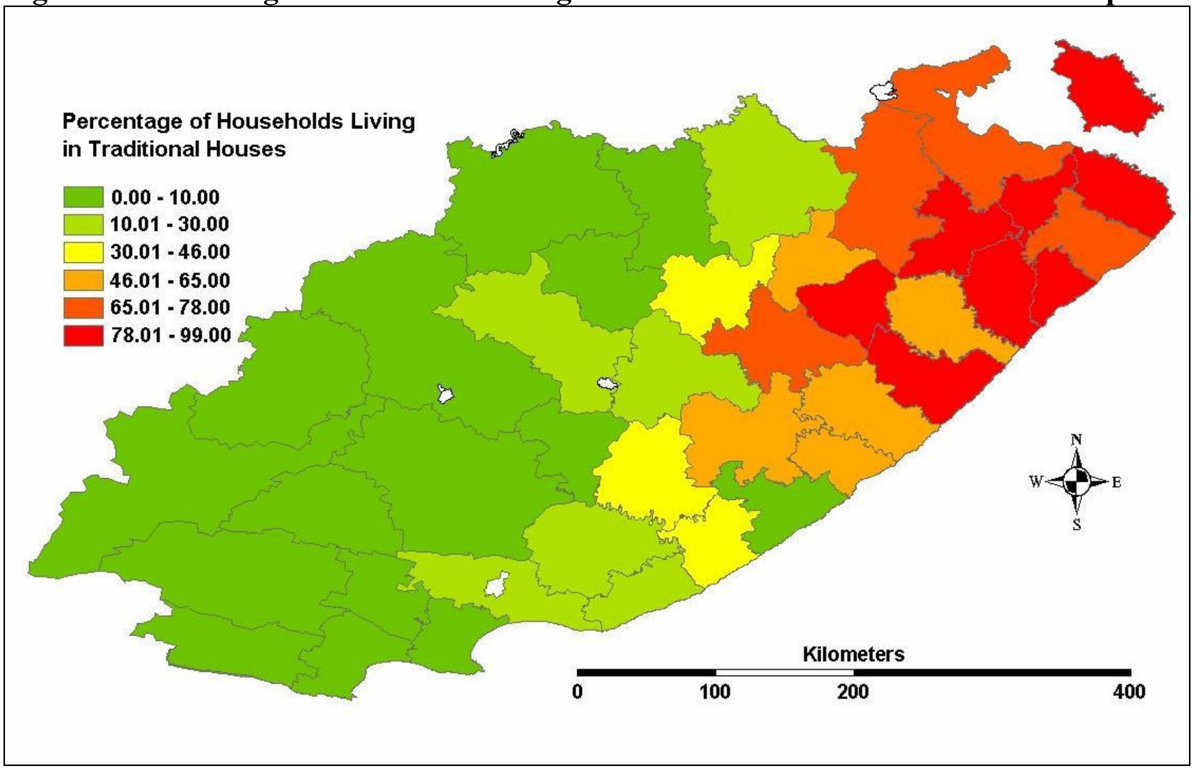
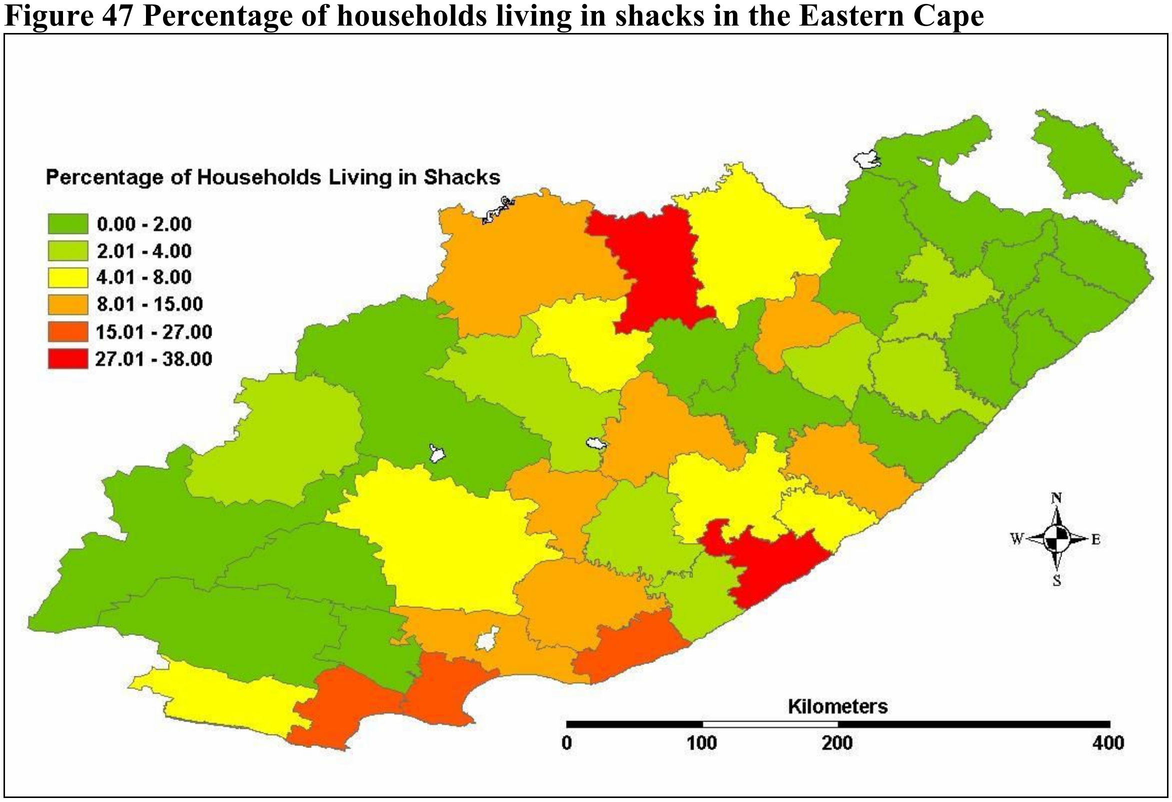


Figure 47 Percentage of households living in shacks in the Eastern Cape



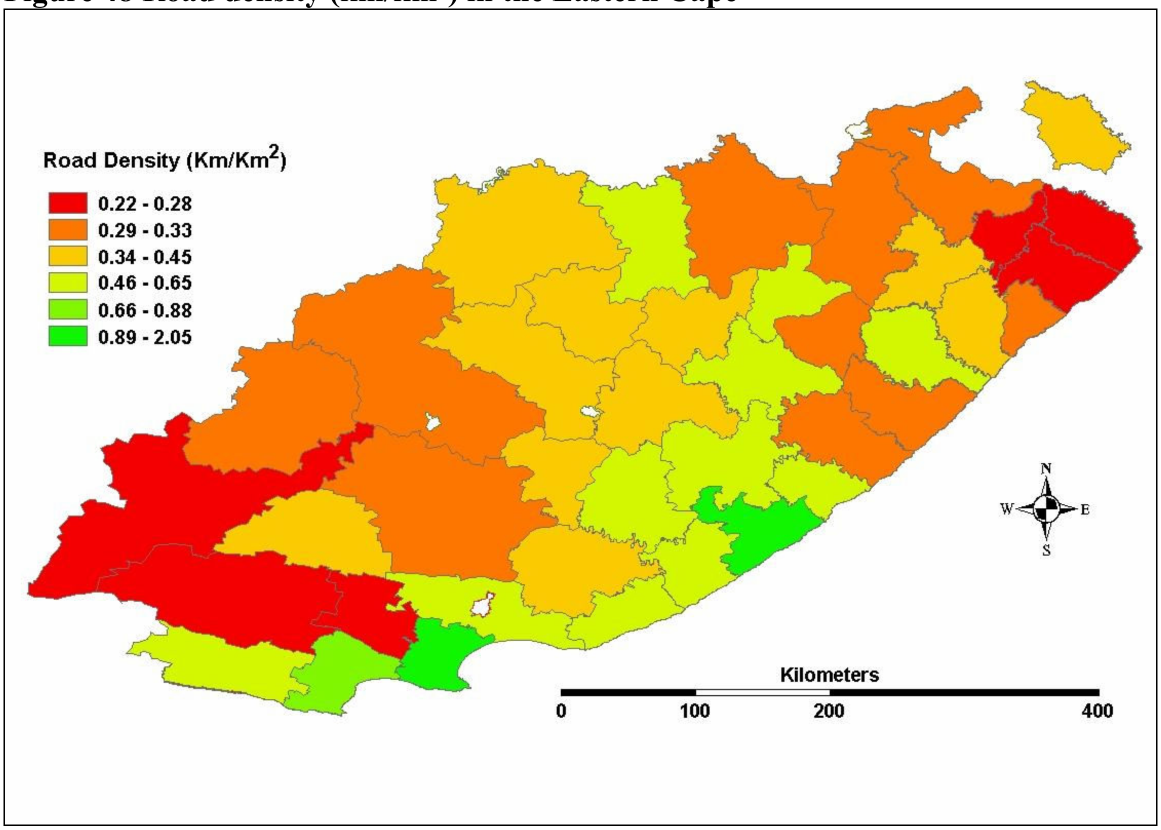
assumption. Importantly, though, shacks constructed from very flimsy materials appear to be more vulnerable compared with more sturdy traditional homes constructed from mud, thatch and, more recently, corrugated-iron roofs. However, a recent survey of building damage at Sitebe village, which was struck by a severe storm in January 2006, reveals that even a well-constructed community hall was severely damaged. This confirms the belief that severe storms may cause severe damage to all kinds of building structures, regardless of the type of dwelling and the building materials used. In most cases, though, shacks and traditional homes will bear the brunt of storm damage and hence people living in such structures will be more vulnerable (Mpiti, pers. comm., 2006).

Figure 46 shows the percentage of households living in traditional houses, while Figure 47 shows the percentage of households living in shacks. The very high concentration of traditional houses (up to 99%) in the rural eastern areas of the province is most evident, while shacks are generally more frequently encountered in the densely populated urban areas on the coast. Very large informal settlements, comprising mainly shacks, are located around the larger coastal cities (Berry *et al.*, 2004). Interestingly, some parts of the central and northern areas of the province show moderately high to high percentages of households living in shacks; it is suggested that these areas would have large informal settlements surrounding the main central towns, e.g. Aliwal North and Burgersdorp.

8.4.2.2 Road density

Road density is expressed as the total length of roads (national, main and secondary) per km^2. This indicator was chosen as a measure of the accessibility of a community in the event of a severe storm. This is an important factor in determining how rapidly emergency assistance can reach affected areas by road. In many of the remote rural areas of the province, road access is the only means of supplying emergency assistance to storm victims (Mpiti, pers. comm., 2006; Williams, pers. comm., 2006). Figure 48 clearly shows significantly lower road densities in the western and eastern extremes of the province. The researcher suggests that the low densities in the western areas are a function of low population densities in general, whilst the eastern areas are a result of historical under-development combined with difficult mountainous terrain. Given the high population densities and low accessibility in the extreme eastern areas, populations are more likely to be vulnerable there. Compounding the situation in these areas is the very poor condition of secondary (gravel) roads, most of which can be negotiated only by four-wheel-drive vehicles to reach remote villages. During periods of very heavy rain, even four-wheel-drive vehicles are not able to reach isolated communities so the only access is by helicopter, but this is very expensive and is used only as a last resort (Mpiti, pers. comm., 2006).

Figure 48 Road density (km/km^2) in the Eastern Cape



8.4.2.3 Access to communications/early warning capacity

Three indicators were selected to provide an indication of access to communications, *viz.* percentage of households with no access to a telephone (landline and cellular telephone), percentage of households with no radio and percentage of households with no television. Access to a radio, television and telephone are critical factors in determining a community's capacity to receive timeous forecasts and early warnings of an impending storm event via electronic media, and to summon assistance once a storm has occurred.

The SAWS and disaster management in the province are jointly responsible for providing and disseminating timeous early warning to all communities (Poolman, 2006) (*vide* Chapter 4, section 4.3.2).

Figure 49 to Figure 51 provide a very distinct, common pattern of high percentages of households with no access/ownership of telephone, radio and television in the north-eastern areas of the province. The researcher asserts that rural communities living in these areas would be highly vulnerable to the impact of storms without access to early warning of severe storms. Significantly, interviews with inhabitants of rural villages in King Sabata Dalindyebo municipality revealed that weather warnings are generally understood and heeded where households have reasonable access to radio and television.

Figure 49 Percentage of households with no access to telephone in the Eastern Cape

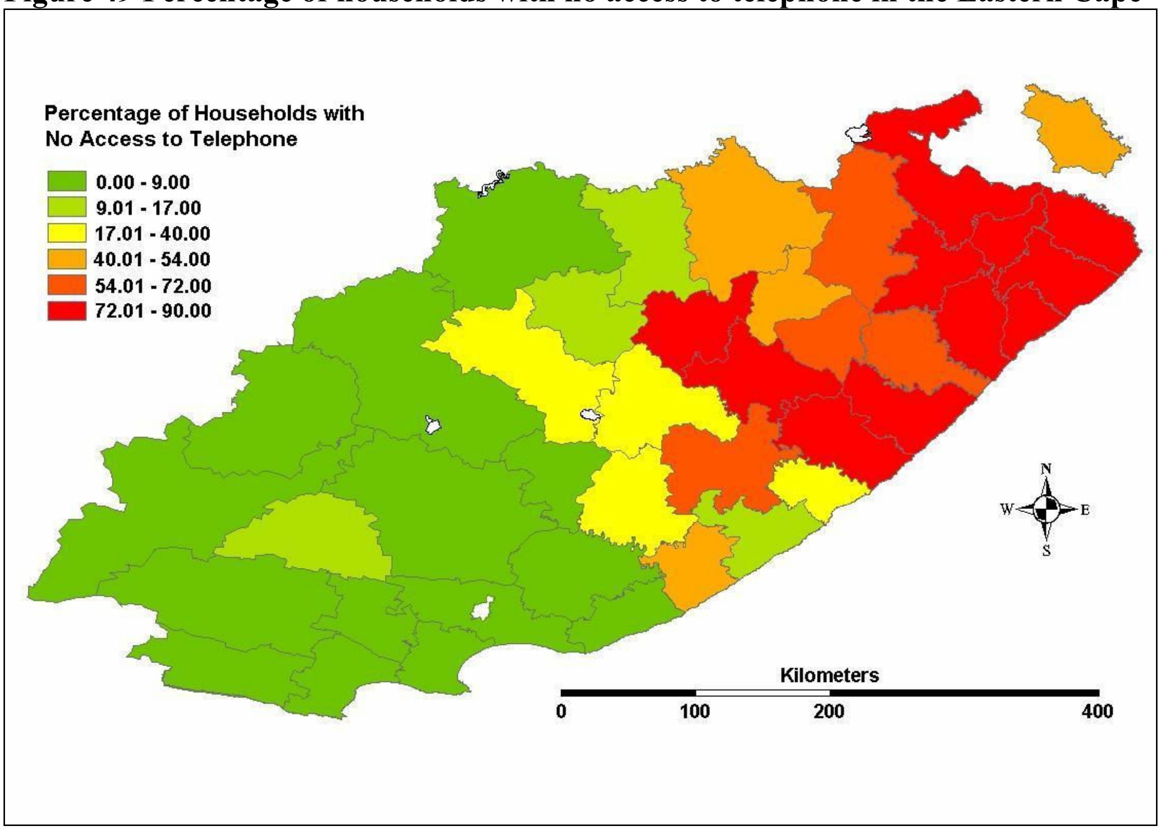


Figure 50 Percentage of households with no radio in the Eastern Cape

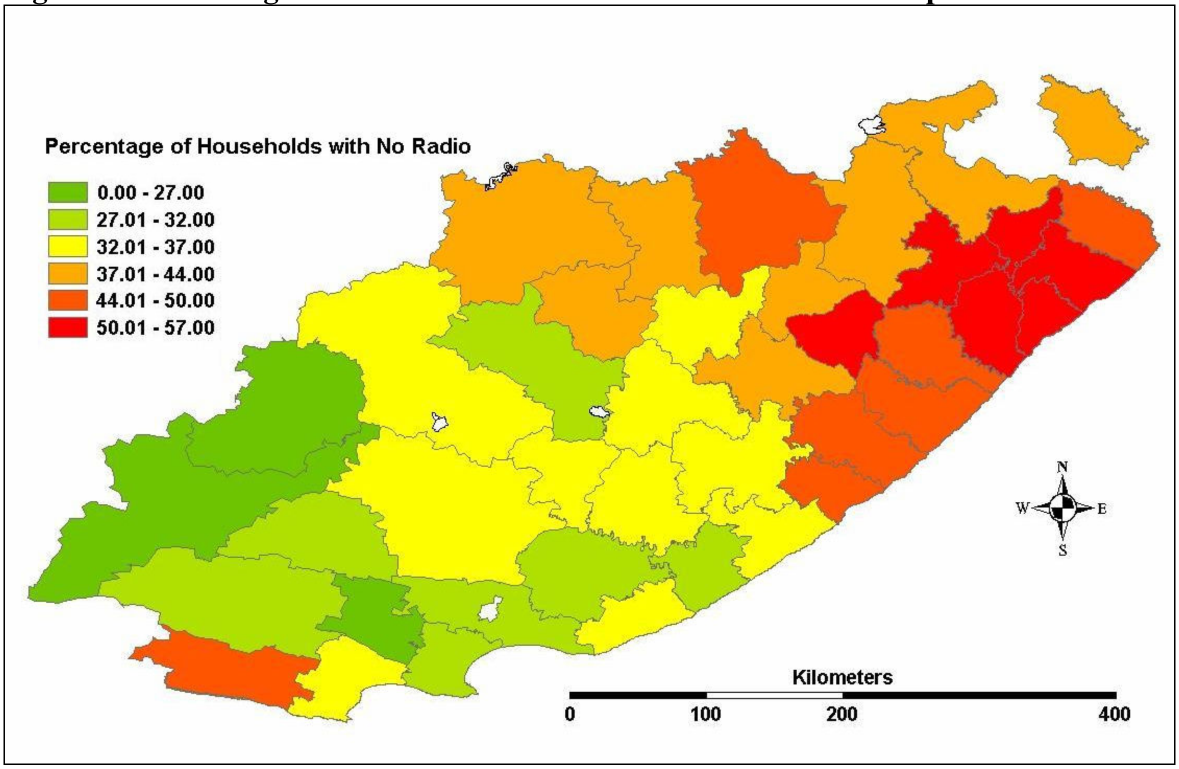
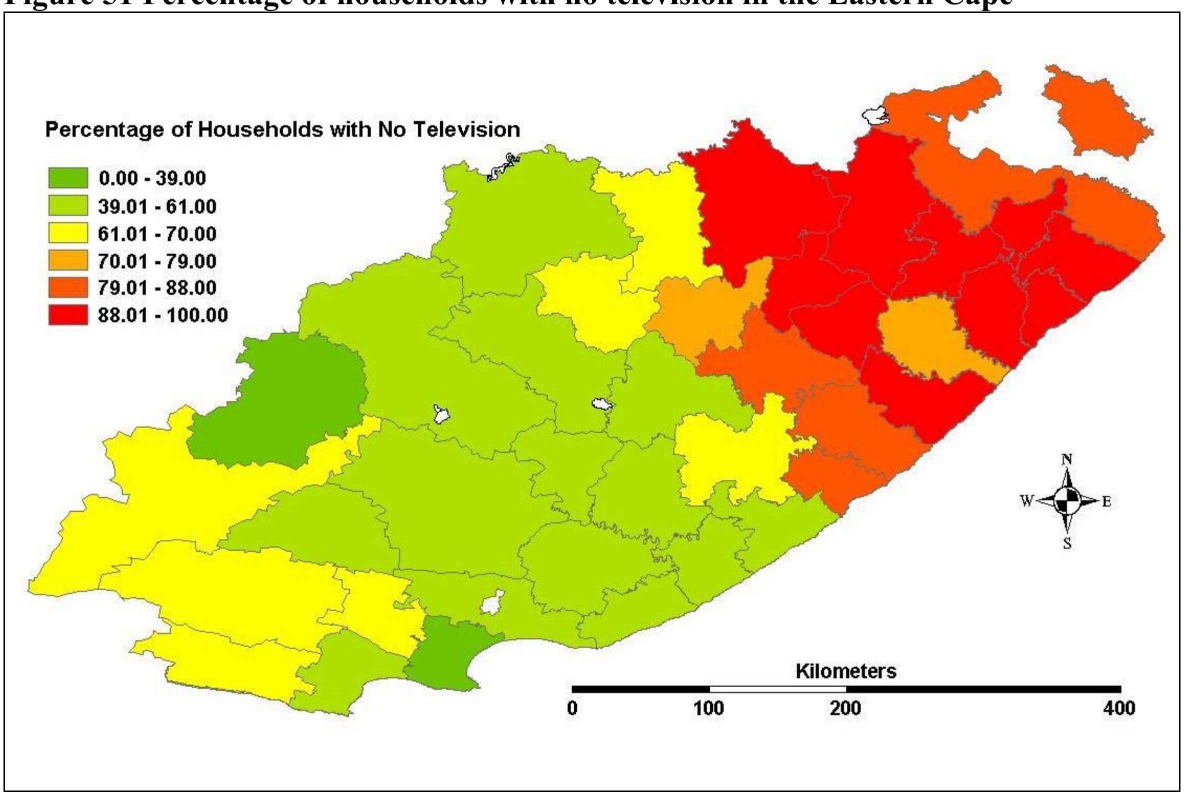


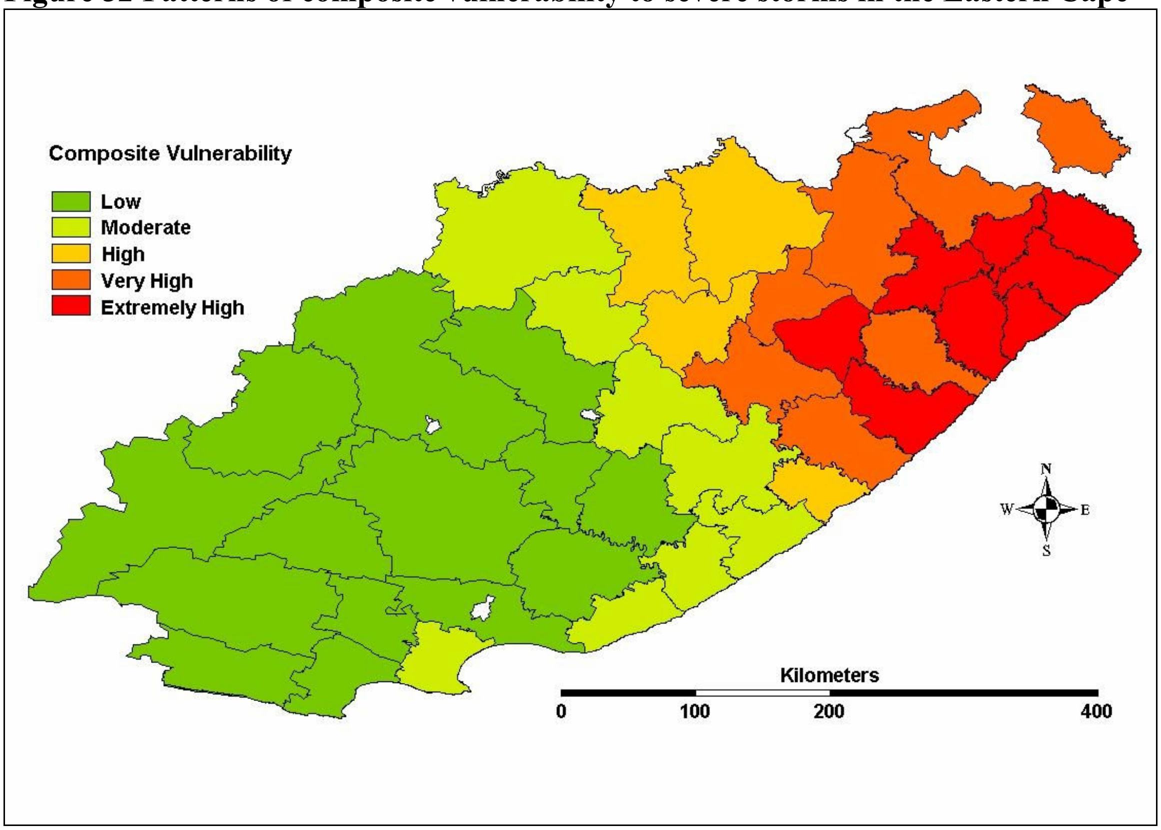
Figure 51 Percentage of households with no television in the Eastern Cape



8.4.3 The pattern of composite vulnerability

Figure 52 shows the pattern of multiple or composite vulnerability for the province at a municipal/district scale. A very distinct pattern of increasing vulnerability from west to east is discernible. Most importantly, a contiguous area corresponding almost exactly with the former Transkei region comprises the most vulnerable municipalities in the province.

Figure 52 Patterns of composite vulnerability to severe storms in the Eastern Cape



On a district level, Cacadu shows a low vulnerability, with the exception of the Nelson Mandela Metro and Ndlambe municipality (Port Alfred and surrounds), which show moderate vulnerabilities. Amatole District shows a range of low vulnerability in the west to extremely high vulnerability in the east (Mbhashe municipality). Chris Hani District shows a similar pattern of low vulnerability in the west and extremely high vulnerability in the east (Engcobo municipality). Ukhahlamba District shows less variation, ranging from moderate vulnerability to very high vulnerability in the east. Significantly, both

Alfred Nzo District (Umzimvubu and Umzimkulu municipalities) and OR Tambo District in the extreme east comprise municipalities of only very high and extremely high vulnerability. Most revealing are the six of the seven municipalities comprising the OR Tambo District which show extremely high vulnerability (Mbizana, Qaukeni, Ntabankulu, Port St Johns, Mhlontlo and Nyandeni), making this the most vulnerable district in the province.

8.5 Summary

This chapter has shown clearly demarcated patterns of socio-economic and physical vulnerability in the province. It has been stressed that the more vulnerable a community, the greater the physical and economic costs of storm impacts. The rural eastern and north-eastern parts of the province reveal the highest composite vulnerabilities; within this area the most vulnerable district is OR Tambo.

CHAPTER NINE: THE ANALYSIS OF RISK

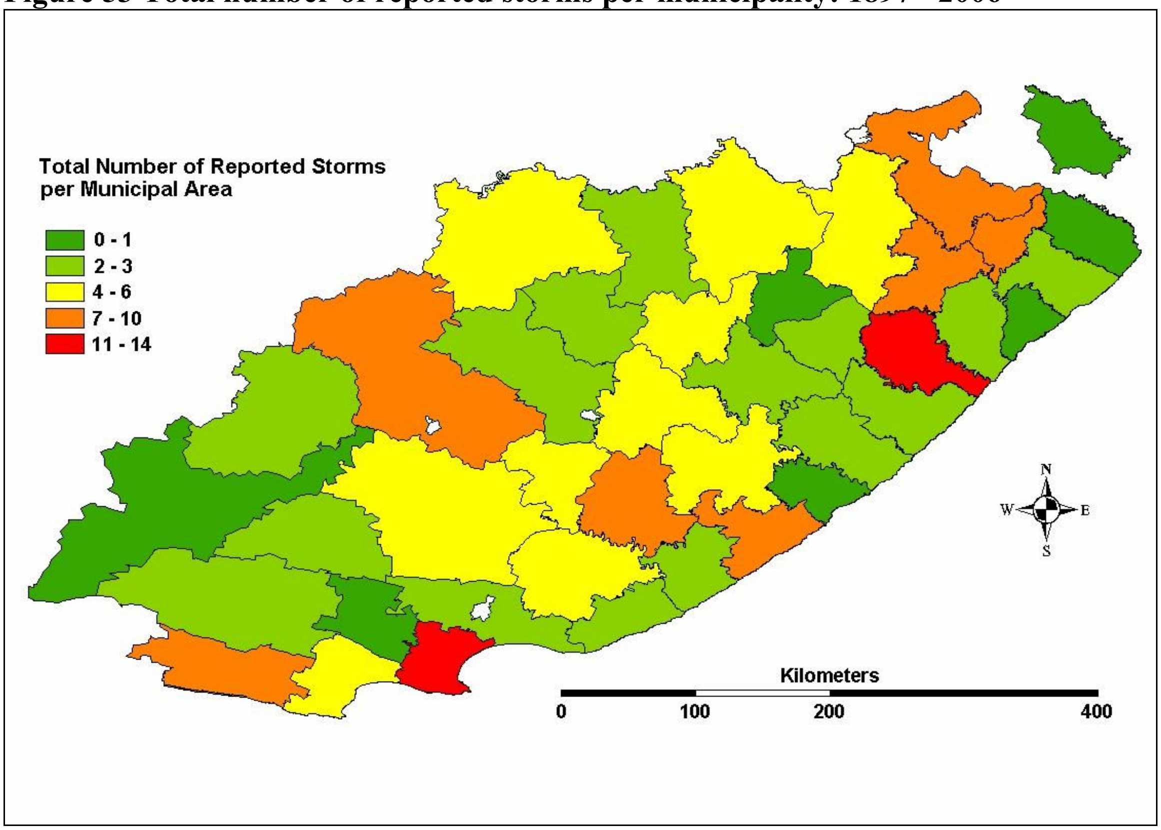
We are all very worried about more storms coming after this one. We have no money to build our huts again. The council gave us nothing.

Nobuzeli Xoto, resident of Sitebe village near Umtata, July 2006

9.1 Introduction

Hazard threat (H), based on reported storm frequencies, has been discussed in Chapter 7. Figure 53 shows the frequency of storms or hazard threat at a municipal scale for the period 1897-2006.

Figure 53 Total number of reported storms per municipality: 1897 - 2006



Vulnerability (V) to the impact of storms, based on 11 indicators, has been shown in Chapter 8 (Figure 52). This chapter examines the product of (H) and (V) in order to establish an overall indication of risk (R) to the various geographic populations of the province.

According to the ISDR (2004;16), risk may be defined as “the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions”.

Five risk categories were defined, based on the product of hazard frequency and vulnerability, *viz.* low, moderate, high, very high and extremely high risk. The statistical method used to derive a risk index for each municipality and the five risk categories is explained in Chapter 6.

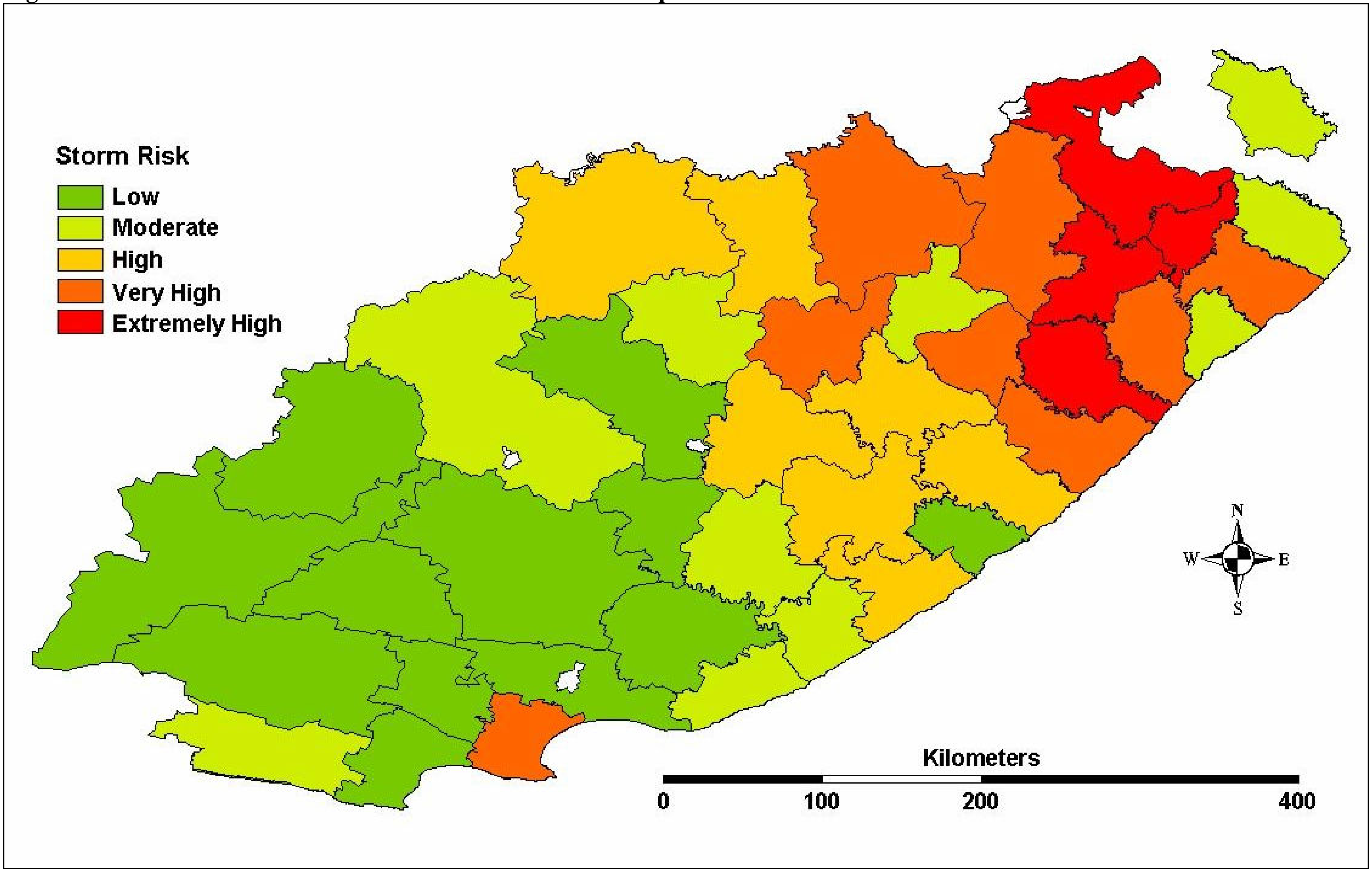
9.2 Patterns of risk

Figure 54 shows the overall pattern of risk for the province at a municipal scale. Higher risk areas are found where both the hazard threat and vulnerability are high, while lower risk areas are found where the hazard threat and vulnerability are low; a gradation from low risk in the west to extremely high risk in the east is clearly shown. Excluding some anomalies, the risk map naturally divides into three broad risk zones: low risk in the western areas, moderate to high risk in the central areas and very high to extremely high risk in the eastern areas. These broad divisions are also clearly demarcated in the composite vulnerability map of the province (Figure 52).

Districts with extremely high risk are OR Tambo (the municipalities of King Sabata Dalindyebo, Mhlontlo and Ntabankulu) and Alfred Nzo (Umzimvubu municipality). Included in these areas is the large urban settlement of Umtata and the smaller rural villages of Mount Ayliff, Tabankulu, Tsolo, Qumbu, Mount Frere and Mount Fletcher, all of which have been mentioned frequently in previous chapters. The risk map clearly demonstrates the compound problem of high storm incidence and extremely high vulnerability in the above areas.

Areas of very high risk are situated immediately to the west and east of the extremely high risk areas; this is a result of high storm frequencies and very high vulnerability.

Figure 54 Patterns of risk to severe storms in the Eastern Cape



Municipalities with a very high risk are Qaukeni, Nyandeni, Mbhashe, Engcobo, Elundini, Senqu and Emalahleni. Further westwards the pattern of risk gradually changes from high to low risk. A large percentage of the Cacadu District in the west shows a low risk; this is a result of low storm incidence and low vulnerability. The Nelson Mandela Metro is an exception in these western parts with a very high risk; the high frequency of reported storms accounts for this. Much of the central parts of the province, situated between the extremes of risk in the west and east, comprise moderate to high risk areas.

Notably, some areas of moderate risk are shown in the extreme north-eastern parts of the Alfred Nzo and OR Tambo districts (Umzimkulu, Mbizana and Port St Johns municipalities); this is a result of very low frequency of reported storms.

9.3 The relationship between risk patterns and impact patterns

Having established a broad pattern of severe storm risk for the province, the relationship between the risk pattern and the historical storm impact patterns from 1897-2006 (already shown in Chapter 7) is examined. Three separate maps were prepared for this purpose: risk areas + total number of storms (the higher impact TS3, TS4 and TS5 categories), risk areas + total number of injuries, and risk areas + total number of deaths. Based on the assumption that areas of higher risk will have been affected more severely by severe storms in the past, high impact areas should correspond reasonably well with high risk areas. Figure 55 to Figure 57 show the results of this analysis.

Figure 55 Relationship between storm incidence and storm risk in the Eastern Cape

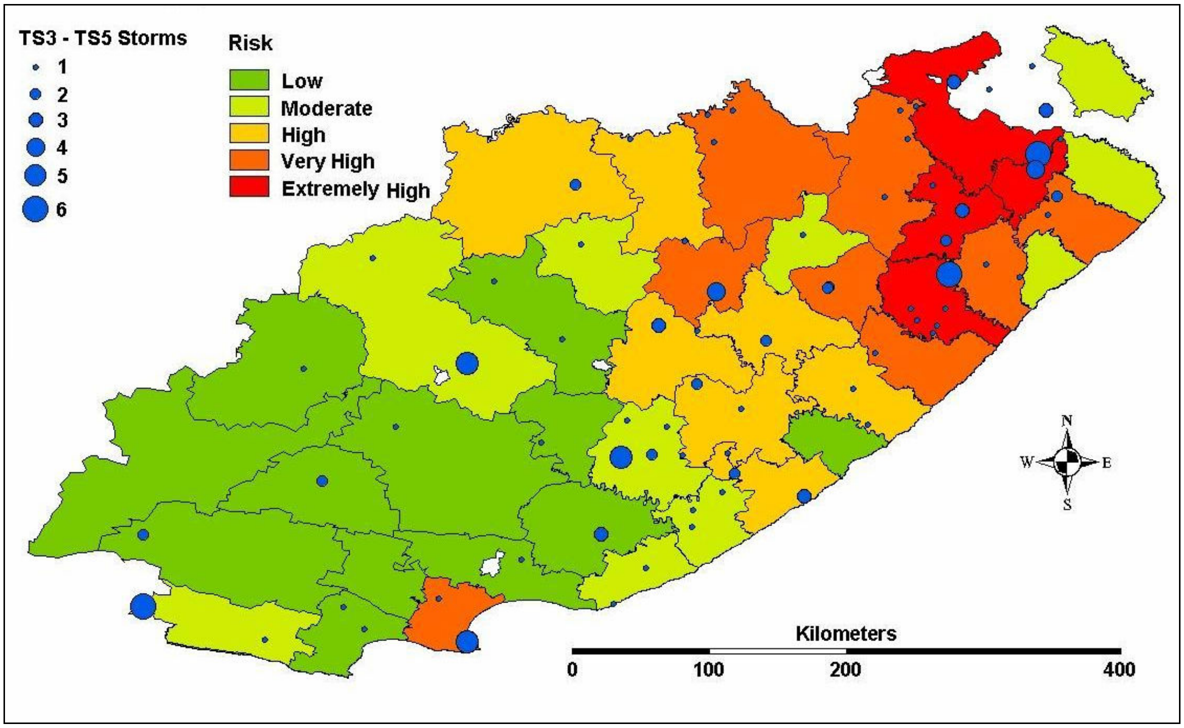


Figure 56 Relationship between total injuries and storm risk in the Eastern Cape

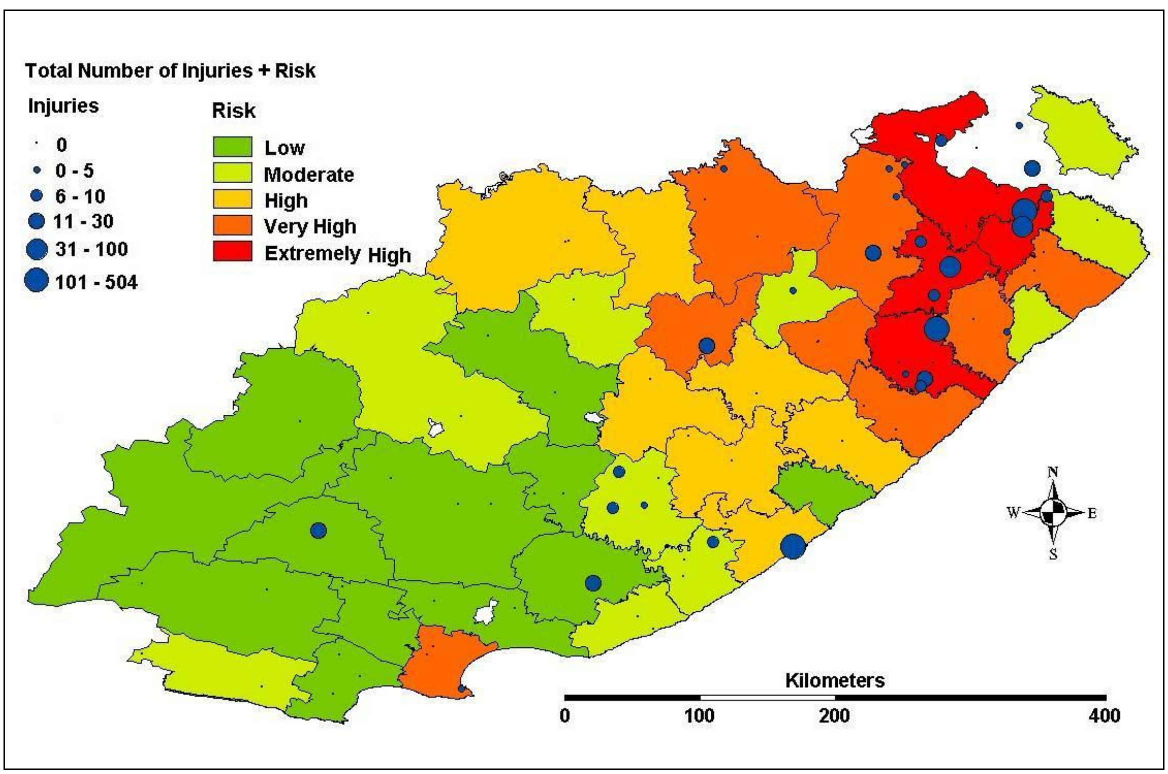
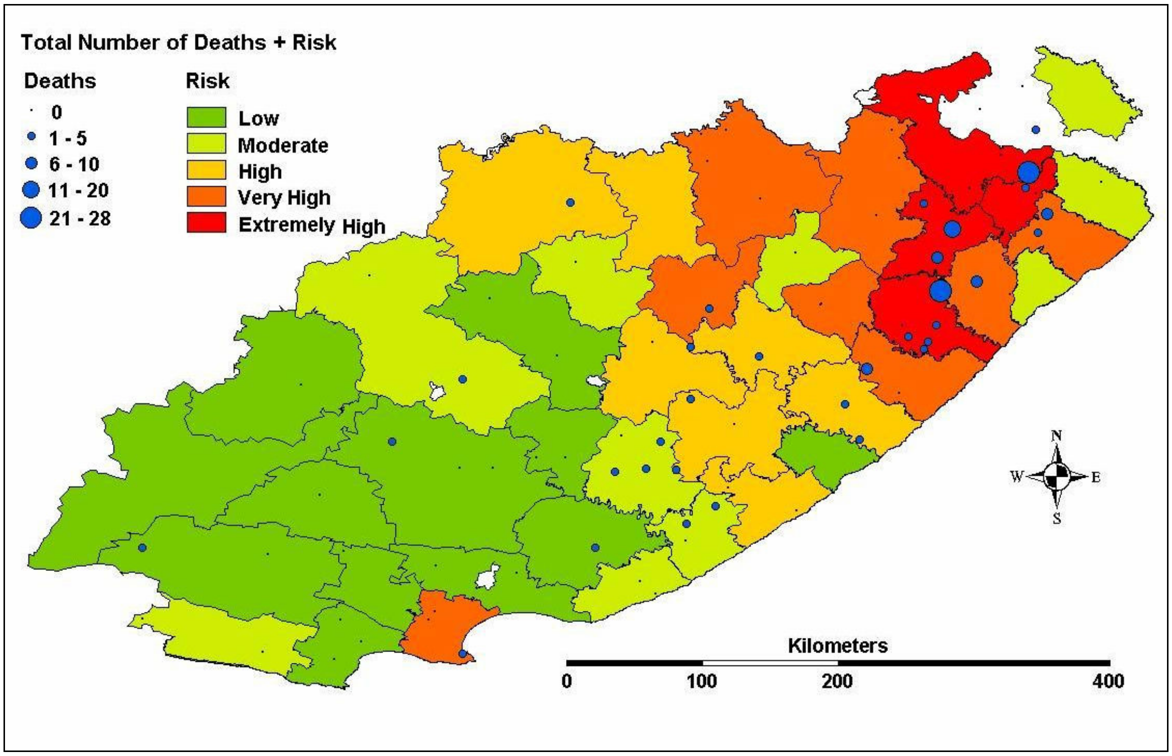


Figure 57 Relationship between total deaths and storm risk in the Eastern Cape



The pattern of total reported storms (TS3-TS5 categories) shows considerable similarity with high, very high and extremely high risk areas in the central and eastern parts of the province (Figure 55). Worth noting is that three of the four TS5 (devastating) category storms have occurred within the highest risk areas in the extreme north-east. In the lower risk areas in the east, Misgund and Cradock show as high impact areas; this is a result of the high economic losses arising from repeated hailstorms in the past.

Significantly, the areas of highest injuries and loss of life correspond remarkably well with the highest risk zones in the extreme eastern areas of the province (Figure 56 and Figure 57). A secondary high injury and loss of life area in the south-central area also corresponds well with moderate to high risk areas.

9.4 Summary

This chapter has illustrated well-defined patterns of risk based on storm frequency and vulnerability. The extreme north-eastern parts of the province clearly show as the highest risk areas, with the western parts as the lowest risk areas. It has been shown, too, that high risk areas correspond very well in general with high impact areas, which have historically high levels of injury, loss of life, loss of livelihood and damage to property and infrastructure. To conclude, Figure 55 to Figure 57 provide validation that the patterns of severe storm risk for the various geographic populations in the Eastern Cape revealed in this chapter accurately reflect the probability of harmful consequences or expected losses resulting from the impact of severe storms.

CHAPTER TEN: CONCLUSION AND RECOMMENDATIONS

> *A black swirling cloud came down on us with no warning. Four of our family huts were destroyed, and one seriously damaged. All my sheep and horses were killed. All my vegetables were flattened. My son's arm was badly injured. We all sleep in one hut now. We have no money to rebuild our huts. The government has given us nothing.*
>
> Madala Basayi, resident of Sitebe Village near Umtata, July 2006

10.1 Introduction

This study focused on severe convective storm risk in the Eastern Cape. The primary aim of the research was to investigate the extent and impact of severe storms in the Eastern Cape and to make recommendations concerning mitigation, early warning and effective disaster risk management and planning in the province. This was achieved by developing a multi-hazards research framework which allowed for the investigation of not only the physical and impact characteristics of severe storms in the Eastern Cape, but also the patterns of vulnerability and risk to various geographic populations.

The researcher strongly asserts that the multi-hazard model of severe storm risk (Figure 2, Chapter 1) and the severe storm classification scheme based on recorded impact (Figure 12, Chapter 6) devised for this study constitute an original and significant contribution to applied hazards research internationally. The classification scheme allows for the ranking of both current and historical severe storm events of all types, which is very important in constructing storm inventories. Furthermore, the researcher strongly contends that both the conceptual model and classification scheme have a potential wider application in further severe weather research, both locally and internationally.

The opening Chapters 1 - 5 provided the context for the study, while Chapter 6 outlined the methods and procedures used to conduct the research, based on the previous chapters. The following key points from these chapters are summarised below.

- The global impact of climate-related disasters is becoming increasingly severe, particularly in the less developed countries of the world. South Africa, too, has witnessed an increase in the number of severe weather impacts in recent years. It has been stressed that, whilst severe convective storms do not exact the same toll in terms of loss of life and injury as other severe weather phenomena such as large-scale flooding, their accumulated impact on highly vulnerable people is significant in this province. Importantly, it has been stressed that there is a lack of severe storm research undertaken from a hazard, vulnerability and risk perspective, both nationally and internationally.
- Despite encouraging developments in South Africa towards implementing the requirements of the enlightened Disaster Management Act of 2002, there are a number of obstacles to overcome; these are particularly related to the adequate staffing and training of disaster management personnel in remote parts of the country and the ongoing shift in mindset from reactive to proactive disaster risk management. It has been shown, however, that provincial disaster management structures in Eastern Cape have made encouraging progress towards implementing mitigation and prevention measures. Importantly, the South African Weather Service in the province is committed towards improved and more efficient early warning of severe storms.
- A broad range of methods was used to obtain reliable and comprehensive storm reports for the Eastern Cape. Problems of data quality related to this type of research were discussed and methods to improve data reliability were outlined, in particular the use of multiple sources of information and the process of ground-truthing by means of personal interviews and field research. The researcher strongly asserts that the inclusion of both physical hazard and socio-economic/vulnerability variables in the GIS analysis of storm risk at a municipal, district and provincial scale constitutes pioneering research in South Africa and marks an important contribution to GIS hazard research internationally.
- Rigorous and objective methods were used to obtain, process, categorise and analyse the storm data. The rationale and method was provided for developing a storm severity classification for this study, based on recorded impact. The researcher is of the opinion that this classification scheme proved to be extremely valuable in

revealing the differential impact pattern of severe storms in the province and is a significant outcome of the study in its own right. It is suggested that the classification scheme has the potential to be adapted to a variety of severe weather study contexts.

10.2 The results of the study

Chapter 7 presented the analysis of the spatial and temporal distribution patterns of storm hazard, based on the 179 reported storm events from 1897-2006. The key findings were:

- The number of reported storm events in the province has increased since 1981; most noticeably from 1992. This is most likely as a result of improved reporting of storms, particularly in the rural areas of the former Ciskei and Transkei self-governing territories. Historical under-reporting of storms in these eastern areas prior to 1992 has resulted in a skewed distribution pattern for the time series.
- The number of reported storms of greater impact (TS3-TS5 category storms) has increased markedly since 1981.
- The geographic distribution of storms is concentrated in the rural eastern and north-eastern parts of the province.
- A higher frequency of reported storms is found in the eastern areas since 1992.
- Storm impacts (loss of life and injury, loss of livelihood and damage to infrastructure) are significantly more severe in the rural eastern areas of the province.
- Lightning accounts for a disproportionately high loss of life and injury in the extreme north-eastern parts. This is true despite the fact that lightning events are most likely to be significantly under-reported.
- Hailstorms are the most frequently reported hazard and account for significant economic losses to commercial farmers in the central and western parts of the province, in particular.

Chapter 8 presented an analysis of the pattern of socio-economic and physical vulnerability to severe storms in the province. The key findings were:

- Highest composite vulnerabilities are concentrated in the rural eastern and north-eastern parts of the province.
- The province naturally separates into three well-defined vulnerability zones: low vulnerability in the western parts, moderate to high vulnerability in the central parts and very high to extremely high vulnerability in the eastern parts.
- The most vulnerable district in the province is OR Tambo in the extreme north-east.

Chapter 9 presented an analysis of the pattern of risk to severe storms in the province. The key findings and outcomes were:

- Higher risk areas are found where both high hazard threat and high vulnerability coincide; a gradation from low risk in the west to extremely high risk in the east is clearly demarcated – three similar risk zones are apparent as shown in the vulnerability patterns.
- Districts with extremely high risk are concentrated in the north-east: OR Tambo and Alfred Nzo.
- These areas of highest risk correspond very well, in general, with high impact areas that have historically high levels of injury and loss of life, loss of livelihoods and damage to property and infrastructure.
- A major outcome of the study is the production of a severe convective storm risk map of the Eastern Cape (Figure 54), which it is hoped will be of benefit to a number of stakeholders in the province, particularly disaster management, but also the South African Weather Service, agricultural organisations, development/planning authorities, educational authorities and risk insurers. It is hoped that this map and the study in general will assist in guiding the operational responses of the various authorities, especially in terms of those interventions aimed at disaster risk reduction in the Eastern Cape.

10.3 Recommendations arising from the study

The results of this study have pointed to a need for strengthening institutional capacities in a number of spheres to prevent and mitigate the impact of storms in the Eastern Cape. In particular, the following aspects need addressing:

- Strengthening institutional capabilities in the more remote rural parts of the province to provide effective prevention and mitigation in high risk areas.
- Improving communication of early warnings of rapid-onset severe storms to high risk remote rural areas. This can be achieved by installing more public telephones in remote areas, using local radio stations to disseminate warnings and by having a better organised system of key contacts, such as community liaison officers, who would be able to disseminate warnings more effectively to local communities. Given the quick onset of severe storms, timeous warning is a critical factor in mitigating their impact on communities.
- Educating communities in the rural areas about severe storm hazards and precautions to be taken in the event of severe storms. Suggested examples of education initiatives include making use of teachers and schools (as part of the curriculum), distributing information brochures at clinics, community centres and shops, education "roadshows" by disaster management practitioners, *etc.*
- Improving the recording and tracking of severe storm events by disaster management authorities. Although reporting of events has improved, there is still no systematic method of recording and keeping an inventory/database of storms and related impacts at an institutional level. It is suggested that this be broadened to include all severe weather impacts, not only severe storms. Such a crucial task needs to be centralised at the provincial disaster management centre in Bisho. At a national level, the National Disaster Management Centre in Pretoria needs to assume the responsibility of maintaining a national register of severe weather events, as stipulated in the Disaster Management Act (2002). To the researcher's knowledge, this key responsibility has not been assumed yet in any systematic way at provincial or national level.
- Implementing medium to long-term developmental programmes by the state and provincial government aimed at decreasing the vulnerability of marginalised

populations, particularly in the eastern parts of the province. This study has clearly shown the very high levels of vulnerability to storm impacts in the impoverished rural areas of the province. Developmental programmes need to be expedited in order to build resilience and to raise the general standard of living of poor rural communities. This should include, *inter alia*:

- Accelerating programmes to build more robust houses that can withstand the impact of severe storms.
- Improving health services, in particular the number of clinics and hospitals to deal with injuries resulting from severe storms.
- Upgrading the condition of secondary gravel roads to facilitate better access to communities by emergency services in the event of storms.
- Improving the general level of education of rural communities, including adult education initiatives.
- Creation of sustainable work opportunities to raise the income level of rural communities. It is recognised that this is an exceptionally difficult objective to achieve, even in the long term, given the historical impoverishment of the former Transkei and Ciskei areas. Nonetheless, the researcher is of the opinion that poverty reduction is the single most important long-term strategy in building resilience and capacity in communities to withstand the impact of storms.

Furthermore, the researcher suggests that in light of the results of this study, further research on severe weather events in the province should include:

- Other severe weather hazards, such as cut-off lows, mid-latitude cyclones, cold spells, drought, *etc.* It is also suggested that further studies be approached from a similar hazards conceptual framework used in this study. It is recommended that future studies which require historical research into severe events should use the same methods used in this study to mitigate the problem of data unreliability. This can be achieved to some degree, firstly, by consulting the widest possible range of sources to validate storm reports and, secondly, by conducting extensive field research and interviews to ground-truth assumptions *in situ.*

- A focused and detailed study on lightning hazard in the province.
- Detailed studies on local-scale variations in vulnerability and storm risk. This study has not captured the local nuances in storm risk yet local assessments are seen as a critical component of municipal integrated development plans.
- Assessment frameworks which introduce additional complexity by including a range of institutional factors and mechanisms that may play a role in either reducing or building the capacity of communities to withstand the impact of storms.
- Assessment of indigenous knowledge, perceptions and coping mechanisms with respect to severe storms in rural areas. Effective early warning systems require information and knowledge on how warnings are understood and interpreted by at-risk communities and how this is translated into action. It is critically important that education and disaster planning initiatives must try to bridge local knowledge with scientific/expert knowledge.

10.4 Conclusion

One of the more certain aspects of global climate change scenarios is an increase in the incidence of severe weather events. The implications of this for South Africa are very serious, given the significant impact of severe weather over the past number of years. Whilst humans may not be able to change the natural course of events, concerted action at a political and institutional level would most certainly help to build capacity and reduce people's vulnerability to severe weather impacts. The researcher asserts that every effort must be made to implement the full scope of proactive measures contained in the Disaster Management Act (2002) within a reasonable timeframe. Should the political will be found to expedite this process, much progress will have been made towards alleviating the suffering of the most vulnerable populations caused by the recurrent bouts of severe storms in this province.

When the summer storms strike again, one can only hope that Madala Basayi's refrain "the government has given us nothing" will be heard no more in Sitebe Village nor in any of the rural villages of the Eastern Cape.

PERSONAL COMMUNICATIONS

Adonis, B., October 2001, headmaster, Laer Blinkwater, Fort Beaufort, Republic of South Africa.

Arnold, M., April 2005, owner of the farm "Grandon", Bathurst, Republic of South Africa.

Basayi, M., July 2006, resident, Sitebe village, Umtata area, Republic of South Africa.

Brooks, H., June 2005, Head: Mesoscale Application Group, NOAA/NSSL, Norman, United States of America.

Dotzek, N., September 2005, Research Scientist, DLR-Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany.

Giaiotti, D., September 2006, Climatologist, ARPA FVG OSMER (Regional Meteorological Observatory), Visco, Italy.

Hansen, N., February 2000, disaster management officer, Amatole District Disaster Management, East London, Republic of South Africa.

Holloway, A., June 2005, Director, DiMP, University of Cape Town, Cape Town, Republic of South Africa.

MacGregor, H., October 2004, Researcher, DiMP, University of Cape Town, Cape Town, Republic of South Africa.

Martin, F., November 1998, former Officer-in-Charge, Port Elizabeth Weather Office, Port Elizabeth, Republic of South Africa.

Mhlawuli, S., July 2006, resident, Sitebe village, Umtata area, Republic of South Africa.

Morris, R., August 2006, former resident missionary in Mount Ayliff, Republic of South Africa.

Mpiti, M., July 2006, Senior Disaster Management Officer, OR Tambo District Municipality, Umtata, Republic of South Africa.

Msetu, J., October 2001, resident, Laer Blinkwater, Fort Beaufort, Republic of South Africa.

Nel, J., April 2006, owner of the farm "De Hoogte", Somerset East, Republic of South Africa.

Painter, C., June 2006, owner of the farm “Riverside”, Fort Beaufort, Republic of South Africa.

Paton, J., December 2002, manager, Hobbiton-on-Hogsback Education Centre, Hogsback, Republic of South Africa.

Rae, K., March 2003, Assistant Director: Forecasting, South African Weather Service, Pretoria, Republic of South Africa.

Reid, P., October 2006, Pat Reid Disaster Management Consulting, Port Elizabeth, Republic of South Africa.

Roberts, L., June 2006, owner of “Argyle Farm”, Fort Beaufort, Republic of South Africa.

Sampson, G., May 2006, Climate Information Liaison Officer, South African Weather Service, Port Elizabeth, Republic of South Africa.

Van Niekerk, H., May 2006, Regional Manager: Eastern Cape, South African Weather Service, Port Elizabeth, Republic of South Africa.

Williams, M., July 2006, Assistant Director: Disaster and Fire Section, OR Tambo District Municipality, Umtata, Republic of South Africa.

Xoto, N., July 2006, resident, Sitebe village, Umtata area, Republic of South Africa.

REFERENCES

Adams, L., 1993: A rural voice: Strategies for drought relief, *Indicator South Africa,* 10, 4, 41-46.

Admirat, P., Goyer, G.G., Wojtiw, L., Carte, E.A., Roos, D. and Lozowski, E.P., 1985: A comparative study of hailstorms in Switzerland, Canada, and South Africa, *Journal of Climatology,* 5, 1, 35-51.

African Centre for Disaster Studies, 2005: *African Centre for Disaster Studies: Introduction*, [online], available: http://www.acds.co.za/index.html [12/07/2005].

African Union / New Partnership for Africa's Development (AU/NEPAD), 2004: *Disaster risk for sustainable development in Africa: Africa regional strategy for disaster risk reduction,* African Union and New Partnership for Africa's Development, United Nations / International Strategy for Disaster Reduction Africa, Nairobi, Kenya.

Alexander, D., 1993: *Natural disasters,* UCL Press, London.

Alexander, D., 1997: The study of natural disasters, 1977-1997: Some reflections on a changing field of knowledge, *Disasters,* 21, 4, 284-304.

Alexander, W.J.R., 1999: *Risk and society: An African perspective,* commissioned by the Secretariat for the International Decade for Natural Disaster Reduction for the United Nations IDNDR Programme Forum 1999, Geneva, Switzerland, Department of Civil Engineering, University of Pretoria, Republic of South Africa.

Alexander, W.J.R., 2001: *Floods, droughts, poverty, and science*, [online], available: http://www.scienceinafrica.co.za/2001/september/floods.htm [06/10/2006].

Anderson, M.B. and Woodrow, P.J., 1998: *Rising from the ashes: Development strategies in times of disaster,* Intermediate Technology Publications, London.

ArcView (Version 9.1), 2004: *Environmental Systems Research Institute*, Redlands, United States of America.

Bennett, J., 1999: Could Transkei twisters carry the seeds of a better future? *The Sunday Times,* January 31, 1999, p.18.

Berry, M.G., Robertson, B.L. and Campbell, E.E., 2004: Aspects on the history and development of informal settlements in the South-Eastern Cape Coastal Zone, *South African Geographical Journal,* 86, 1, 23-29.

Berz, G., 2000: *Natural catastrophes 2000* [online], available: http://www.munichre.c...medien_e/pm_artikel.html [13/01/2001].

Blaikie, P., Cannon, T., Davies, I. and Wisner, B., 1994: *At risk: Natural hazards, people's vulnerability, and disasters,* Routledge, London.

Bogardi, J.J. and Kundzewicz, W. (eds.), 2002: *Risk, reliability, uncertainty, and robustness of water resource systems,* Cambridge University Press, Cambridge.

Brauch, H.G., 2005: Threats, challenges, vulnerabilities, and risks, *Studies of the University: Research, Counsel, Education,* No.1, United Nations University: Institute for Environment and Human Security, Bonn, Germany.

Brooks, H.E., 2004: Estimating the distribution of severe thunderstorms and their environments around the world, *Preprints,* International Conference on Storms, Brisbane, Queensland, Australia.

Brooks, H.E., 2005: *The what, when, and where of severe thunderstorms and tornadoes,* conference presentation, National Association of Mutual Insurance Companies Conference, Clearwater Beach, United States of America.

Brooks, H.E. and Doswell III, C.A., 2001: Some aspects of the international climatology of tornadoes by damage classification, *Atmospheric Research,* 56, 191-201.

Brooks, H.E., Lee, J.W. and Craven, J.P., 2003: The spatial distribution of severe thunderstorm and tornado environments from global re-analysis data, *Atmospheric Research,* 67-68, 73-94.

Brooks, N., 2003: *Vulnerability, risk and adaptation: A conceptual framework*, Working Paper No. 38, Tyndall Centre for Climate Change Research and Centre for Social and Economic Research on the Global Environment, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom.

Browning, K.A. and Foote, G.B., 1976: Airflow and local growth in supercell storms and some implications for hail suppression, *Quarterly Journal of the Royal Meteorological Society,* 102, 499-534.

Browning, K.A. and Ludlam, F.H., 1962: Airflow in convective storms, *Quarterly Journal of the Royal Meteorological Society,* 88, 117-135.

Bryant, E., 1991: *Natural hazards,* Cambridge University Press, Cambridge.

Burton, I. and Kates, R.W., 1964: *The environment as hazard, 2nd Edition,* Guilford, New York.

Burton, I., Kates, R.W. and White, G.F., 1978: *The environment as hazard,* Oxford University Press, New York.

Carrara, A., Guzzetti, F., Cardinal, M. and Reichenbach, P., 1999: Use of GIS technology in the prediction and monitoring of landslide hazard, *Natural Hazards,* 20, 117-135.

Carte, A.E. and Held, G., 1978: Variability of hailstorms on the South African Plateau, *Journal of Applied Meteorology,* 17, 365-373.

Concannon, P.R., Brooks, H.E. and Doswell III, C.A., 2000: *Climatological risk of strong and violent tornadoes in the United States*, conference presentation, Second Conference on Environmental Applications, American Meteorological Society, Long Beach, United States of America.

Cozett, S., 2000: *Manenberg – a recipe for disaster*, unpublished honours thesis, University of Cape Town, Republic of South Africa.

Crisp, C.A., Janisch, P.R., Carbin, G.W. and Just, A., 2001: *Severe thunderstorm events,* National Oceanic & Atmospheric Administration / Office of Oceanic & Atmospheric Research / National Severe Storms Laboratory, Norman, United States of America.

Cutter, S.L., 1993: *Living with risk: The geography of technological hazards,* Edward Arnold, London.

Cutter, S.L., 1996: Vulnerability to environmental hazards, *Progress in Human Geography,* 20, 4, 529-539.

Cutter, S.L., Thomas, D.S.K., Cutler, M.E., Mitchell, J.T. and Scott, M.S., 1999: *South Carolina: Atlas of environmental risks and hazards*, Department of Geography Hazards Research Lab, University of South Carolina Press, Columbia.

D'Abreton, P., 1991: A synoptic characterisation of some South African tornadoes, *South African Journal of Science,* 87 January/February, 56-61.

De Coning, E. and Adam, B., 2000: The tornadic thunderstorm activity during the 1998-1999 South African summer, *Water SA,* 26, 3, 361-376.

Disaster Mitigation for Sustainable Livelihoods Programme, 2001: [online], available: http://www.egs.uct.ac.za/dimp/html. [10/01/2001].

Disaster Mitigation for Sustainable Livelihoods Programme, 2003: *March 2003 cut-off low: Consolidated report,* Department of Environmental and Geographical Science, University of Cape Town, Republic of South Africa.

Doswell III, C.A., 2003: Societal impacts of severe thunderstorms and tornadoes: Lessons learned and implications for Europe, *Atmospheric Research,* 67-68, 135-152.

Dotzek, N., Grieser, J. and Brooks, H., 2003: Statistical modelling of tornado intensity distributions, *Atmospheric Research,* 67-68, 163-187.

Downing, T.E., 2000: *Toward a vulnerability science*? IHDP Update Newsletter 3/00, 16-17, Environmental Change Institute, Oxford University, United Kingdom.

Eastern Cape Socio-Economic Consultative Council, 2002: *Nkonkobe Local Municipality Integrated Development Plan March 2002,* Bisho, Republic of South Africa.

Elsom, D.M., 2001: Deaths and injuries caused by lightning in the United Kingdom: analyses of two databases, *Atmospheric Research,* 56, 1-4, 325-334.

Elsom, D.M., Meaden, G.T., Reynolds, D.J., Rowe, M.W. and Webb, J.D.C., 2001: Advances in tornado and storm research in the United Kingdom and Europe: the role of the Tornado and Storm Research Organisation, *Atmospheric Research,* 56, 1-4, 19-29.

Fara, K., 2000: *How natural are 'natural disasters'? Vulnerability to drought in southern Namibia communal areas*, unpublished Masters thesis, University of Cape Town, Republic of South Africa.

Ferreira, C.E., 1990: The management of environmental disasters: A case study of the September 1987 floods in Natal and KwaZulu, unpublished Masters thesis, Department of Geography, University of Pretoria, Republic of South Africa.

Feuerstein, B., Dotzek, N. and Grieser, J., 2005: Assessing tornado climatology from global tornado intensity distributions, *Journal of Climate,* 18, 585-596.

Fraile, R., Berthet, C., Dessens, J. and Sanchez, J.L., 2003: Return periods of severe hailfalls computed from hailpad data, *Atmospheric Research,* 67-68, 189-202.

Freeman, C., 1984: Drought and agricultural decline in Bophuthatswana, in South African Research Services (ed.), *South African Review 2,* Ravan, Johannesburg, 284-289.

Freeman, C., 1988: *The impact of drought on rural Tswana society*, unpublished Masters thesis, University of the Witwatersrand, Johannesburg, Republic of South Africa.

Fujita, T.T., 1971: *Proposed characterisation of tornadoes and hurricanes by area and intensity,* SMRP Research Paper No. 91, University of Chicago, United States of America.

Fujita, T.T., 1973: *Experimental classification of tornadoes in FPP scale,* SMRP Research Paper No. 98, University of Chicago, Illinois, United States of America.

Geer, I.W. (ed.), 1996: *Glossary of weather and climate with related oceanic and hydrologic terms,* American Meteorological Society, Boston, United States of America.

Gill, T., 2006: *The South African Weather Service Lightning Detection Network,* conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Goliger, A.M. and de Coning, E., 1999: *Tornado cuts through Cape Flats (29 August 1999),* Division of Building and Construction Technology, CSIR, Pretoria, Republic of South Africa.

Goliger, A.M., Milford, R.V., Adam, B.F. and Edwards, M., 1997: *Inkanyamba: tornadoes in South Africa,* Division of Building Technology, CSIR and South Africa Weather Bureau, Pretoria, Republic of South Africa.

Gregoric, G., Irsic, M. and Zgonc, T., 2003: Survey of convective supercell in Slovenia with validation of operational model forecasts, *Atmospheric Research,* 67-68, 261-271.

Hewitson, B., 2006: *Climate change: An extreme event,* conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Hewitt, K., 1997: *Regions of Risk: A geographical introduction to disasters,* Addison Wesley Longman, Harlow.

Holloway, A., 1999: Africa: Risk prone, but not disaster-affected? in Ingelton, J. (ed.), *Natural disaster management: A presentation to commemorate the International Decade for Natural Disaster Reduction 1990-2000,* Tudor Rose, Leicester, 207-209.

Holloway, A., 2003: Disaster reduction in Southern Africa: Hot rhetoric – cold reality, *African Security Review,* 12, 1, 1-12.

Holloway, A., 2006: *Emerging risk researchers in Africa, ProVention grantee consultation, Meeting Report,* Johannesburg, Republic of South Africa.

Houghton, J., 2004: *Global Warming: The Complete Briefing, 3rd Edition,* Cambridge University Press, Cambridge.

Houghton, J., Ding, Y., Griggs, D.J., Noquet, M., van der Linden, J.P., Dai, X., Maskell, K. and Johnson, C.A. (eds.), 2001: *Climate Change 2001: The Scientific Basis: Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press and the Intergovernmental Panel on Climate Change, Cambridge.

Hundermark, A., 1999: *A Study of South African tornado occurrences in the twentieth century*, unpublished third-year Geography project, Rhodes University, Grahamstown, Republic of South Africa.

Inter-American Development Bank, 2005: *Indicators of disaster risk and risk management,* Summary Report for the WCDR, Program for Latin America and the Caribbean, Inter-American Development Bank-Universidad Nacional de Colombia / Instituto de Estudios Ambientales, Manizales, Colombia.

International Decade for Natural Disaster Reduction, 2000: *Overview,* [online], available: http://www.idndr.org/idndr/overview.html [15/12/2000].

International Strategy for Disaster Reduction, 2004: *Living with risk: A global review of disaster reduction initiatives,* United Nations, International Strategy for Disaster Reduction, Geneva, Switzerland.

International Strategy for Disaster Reduction, 2005: *Hyogo Framework for Action: Building the resilience of nations and communities to disaster – An introduction to the Hyogo Framework for Action,* United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction, Geneva, Switzerland.

International Strategy for Disaster Reduction, 2006: *Disaster reduction in AFRICA: ISDR INFORMS (Issue 6),* Africa Regional Office of the International Strategy for Disaster Reduction, Nairobi, Kenya.

Jackson, J., November 13, 2000: Stormy weather, *Time Magazine,* 156, 20, 32-36.

Jeggle, T., 2001: Evolution as disaster reduction as an international strategy: Policy implications for the future, in Rosenthal, U., Boin, R.A., and Comfort, L.K. (eds.), *Managing crises: Threats, dilemmas, opportunities,* Charles C. Thomas, Springfield, Illinois, 316-341.

Jegillos, S., 1999: Fundamentals of disaster risk management: How are southeast Asian countries addressing these?, in Holloway, A. (ed.), *Risk, sustainable development and disasters,* Periperi Publications, Disaster Mitigation for Sustainable Livelihoods Programme, Department of Environmental and Geographical Sciences, University of Cape Town, Republic of South Africa, 7-16.

Jones, D.K.C., 1991: Environmental hazards, in Bennet, R. and Estall, R. (eds.), *Global change and challenge: Geography for the 1990s,* Routledge, London, 27-56.

Karimanzira, R., 1999: Sustainable development and disasters: challenges for southern Africa, in Holloway, A. (ed.), *Risk, sustainable development and disasters: Southern perspectives,* Periperi Publications, University of Cape Town, Republic of South Africa, 17-24.

Kilian, G., 2005: Summary of disaster management provincial workshops and national workshop, *Disaster Management Southern Africa,* 3, 2, 5.

Kithil, R., 1995: Lightning's social and economic costs, conference presentation, International Aerospace and Ground Conference on Lightning and Static Electricity, Louisville, United States of America.

Koenig, M. and de Coning, E., 2006: Can severe convective storms be anticipated hours in advance? The case of 6 November 2005, conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Kotze, J., 2001: *GIS – A tool for the disaster management practitioner*, conference proceedings, Disaster Management Institute of Southern Africa Conference, Port Elizabeth, Republic of South Africa.

Laing, M., 1999: *A list of most recent tornadoes in S.A.: 1999-1989,* South Africa Weather Service, Pretoria, Republic of South Africa.

Landman, W., 2006: *Introduction to meteorological extremes,* conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Lanken, D., 1996: Funnel fury, *Canadian Geographic,* 116, 4, 24-31.

Le Roux, N.J. and Olivier, J., 1996: Modelling hail frequency using a generalized additive interactive technique, *South African Geographical Journal,* 78, 7-12.

Legates, D.R. and Biddle, M.D., 1999: *Warning response and risk behaviour in the Oak Grove-Birmingham, Alabama, Tornado of 08 April 1998*, Quick Response Report No. 116, Natural Hazards Centre, University of Colorado, Boulder, United States of America.

Lewis, J., 1999: *Development in disaster-prone places,* Intermediate Technology Publications, London.

Loster, T., 1999: Changes in climate and environment, in *Topics 2000: Natural Catastrophes: the current position,* Munich Reinsurance Company, Munich, Germany, 104-112.

MacLean, G.L., 1985: *Roberts' Birds of Southern Africa,* The John Voelcker Bird Book Fund, Cape Town.

Manzato, A. and Morgan, G., 2003: Evaluating the sounding instability with the lifted parcel theory, *Atmospheric Research,* 67-68, 45-473.

Maphanga, K.C., 1997: *People's perceptions of flood hazards and their attitudes towards resettlement: a case study of the community of Azalea in the Greater Edendale Complex, KwaZulu-Natal, South Africa,* unpublished Masters thesis, School of Environment and Development, University of Natal, Durban, Republic of South Africa.

Melching, C.S. and Pilon, P.J. (eds.), 1999: *Comprehensive risk assessment for natural hazards,* WMO/TD No.955, World Meteorological Organization, Geneva, Switzerland.

Meyer, C.L., Brooks, H.E. and Kay, M.P., 2002: A hazard model for tornado occurrence in the United States, *Preprints,* 16th Conference on Probability and Statistics, American Meteorological Society, Orlando, United States of America, J88-J95.

Mitchell, J.K., 1990: Human dimensions of environmental hazards, complexity, disparity and the search for guidance, in Kirkby, A. (ed.), *Nothing to fear,* University of Arizona Press, Tucson, 29-37.

Mgquba, S.K., 1999: *Changing perspectives: from "the natural" to "the vulnerable" and towards disaster management*, unpublished Honours thesis, University of the Witwatersrand, Johannesburg, Republic of South Africa.

Mgquba, S.K., 2002: *The physical and human dimensions of flood-risk: The case of the West Bank, Alexandra Township*, unpublished Masters thesis, University of the Witwatersrand, Johannesburg, Republic of South Africa.

Mgquba, S.K. and Vogel C., 2004: Living with environmental risks and change in Alexandra Township, *South African Geographical Journal,* 86, 1, 30-38.

Montz, B.E., 1994: *Methodologies for analysis of multiple hazard probabilities: An application in Rotorua, New Zealand,* unpublished report on Fulbright Research Scholar Project, Centre for Environmental and Resource Studies, University of Waikato, Hamilton, New Zealand.

Moran, J.M., no date: *Thunderstorms*, American Meteorological Society Education Programme, Washington D.C., United States of America.

Moran, J.M, and Morgan, M.D., 1997: *Meteorology: The atmosphere and the science of weather, fifth edition,* Prentice-Hall, New Jersey.

Munich Reinsurance Company, 2000: *Topics: annual review of natural catastrophes 1999,* Munich, Germany.

Myburgh, D.W., 1991: Geographical perspectives on the drought and flood hazard in the arid and semi-arid region of the Cape Province, unpublished PhD thesis, University of Cape Town, Republic of South Africa.

National Geospatial-Intelligence Agency / GEOnet Names Server, 2006: *GEOnet names server database of foreign place names,* [online], available: http://earth-info.nga.mil/gns/html/index.html [13/01/06].

National Lightning Safety Institute, no date: *Number of deaths by natural hazards, 1940-1981*, [online], available: http//lightningsafety.com/nlsi_lls/stats2.html [15/04/05].

National Oceanic and Atmospheric Administration, no date: *Thunderstorm hazards*, [online], available: http://www.srh.noaa.gov/jetstream/mesoscale/wind.htm [03/10/06].

National Oceanic and Atmospheric Administration, 2006: *NWS plans to implement enhanced Fujita Scale to rate tornadoes*, [online], available: http://spc.noaa.gov/efscale/ [25/04/06].

Natural Hazards Observer, 2005: Contracts and grants: Social vulnerability mapping and GIS in tsunami impact analysis, *Natural Hazards Observer*, XXIX, 6, 21.

Noble, M., Babita, M., Barnes, H., Dibben, C., Magasela, W., Noble, S., Ntshongwana, P., Phillips, H., Rama, S., Roberts, B., Wright, G. and Zungu, S., 2006: *The provincial indices of multiple deprivation for South Africa 2001,* unpublished report, Centre for the Analysis of South African Social Policy, University of Oxford.

Nomdo, C., 2005: *Who helps women cope? Women's agency in households, families and communities,* unpublished Masters thesis, Department of Environmental and Geographical Sciences, University of Cape Town, Republic of South Africa.

Olivier, J., 1988: The relationship between altitude and hail frequency in the Transvaal, *South African Journal of Sciences,* 84, 587-588.

Paul, B.K., 1997: *Survival mechanisms to cope with the 1996 tornado in Tangail, Bangladesh: A case study*, Quick Response Report No. 92, Natural Hazards Centre, University of Colorado, Boulder, United States of America.

Paul, F., 2001: A developing inventory of tornadoes in France, *Atmospheric Research,* 56, 1-4, 269-280.

Peduzzi, P., Dao, H., Herold, C., Rochette, D. and Sanahuja, H., 2001: *Feasibility report on global risk and vulnerability index – Trends per year (GRAVITY)* for United Nations Development Programme/ Emergency Response Division, United Nations Environment Programme / Division of Early Warning and Assessment / Global Resource Information Database, Geneva, Switzerland.

Pelling, M., 2004: *Visions of risk: A review of international indicators of disaster risk and its management: A report for the ISDR Inter-Agency Task force on disaster reduction – Working Group 3: Risk, vulnerability and disaster impact assessment,* United Nations Development Programme and the International Strategy for Disaster Reduction, Geneva, Switzerland.

Perry, A., 1995: Severe hailstorm at Grahamstown in relation to convective weather hazards in South Africa, *Weather,* 50, 6, 211-214.

Poolman, E., 2006: *Disaster risk management plan: South African Weather Service,* South African Weather Service, Pretoria, Republic of South Africa.

Przybylinski, R.W., 2004: *Overview of the WSR-88D Doppler Radar and severe local storms,* workshop presentation, American Meteorological Society Workshop, National Weather Service Training Center, Kansas City, United States of America.

Pyle, D., Rowntree, K. and Fox, R., 1999: *Tornadoes in the Eastern Cape: 1900-1999*, conference presentation, South African Association for Atmospheric Sciences Annual Conference, Richard's Bay, Republic of South Africa.

Qaba, O. and Mafela, T., 1998: *Living in Eastern Cape: Selected findings of the 1995 October household survey,* Central Statistics, Pretoria, Republic of South Africa.

Quarantelli, E.L. and Dynes, R.R., 1976: Community conflict: Its absence and its presence in natural disasters, *Mass Emergencies,* 1, 2, 139-152.

Rae, K., 2005: *Gauteng Hail Data: 1984-1995,* conference presentation, University of Pretoria, Republic of South Africa.

Rae, K. and Clark, L-A., 2005: *Meteosat Second Generation: Severe thunderstorm nowcasting applications. A case study of KwaZulu Natal, 3rd January 2005,* conference presentation, South African Association for Atmospheric Sciences Annual Conference, Richard's Bay, Republic of South Africa.

Red Cross/Red Crescent Climate Centre, 2005: *Report of the 2nd International Work Conference on Climate Change and Disaster Risk Reduction,* Red Cross/Red Crescent Climate Centre, The Hague, Netherlands.

Reid, P., 2005: *Adopting a strategic approach to the implementation of disaster risk management legislation and policy*, conference presentation, Provincial Stakeholders' Disaster Management Working session, Good News Conference, King William's Town, Republic of South Africa.

Republic of South Africa, 1994: *National report of the Republic of South Africa,* IDNDR Mid-Term Review and the 1994 World Conference on Natural Disaster Reduction, Pretoria, Republic of South Africa.

Republic of South Africa, 1998: *Green Paper on Disaster Management*, Department of Constitutional Development, Pretoria, Republic of South Africa.

Republic of South Africa, 1999: *White Paper on Disaster Management*, *Notice 23 of 1999*, Department of Constitutional Development, Pretoria, Republic of South Africa.

Republic of South Africa, 2002: *Disaster Management Act, No. 57 of 2002*, Pretoria, Republic of South Africa.

Republic of South Africa, 2005: *Disaster Management Framework*, Department of Provincial and Local Government, Pretoria, Republic of South Africa.

Roberts, G. and Sampson, G., January 1996: Tornadoes wreak havoc in Fort Beaufort district, *South African Weather Bureau Newsletter*, Pretoria, Republic of South Africa.

Rouault, M., White, S.A., Reason, C.J.C., Lutjeharms, J.R.E. and Jobard, I., 2002: Ocean-atmosphere interaction in the Agulhas Current Region and a South African extreme weather event, *Weather and Forecasting,* 17, 4, 655-669.

Roux, M.S., 2003: *Severe Thunderstorm environments over South Africa*, Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, Republic of South Africa.

SA Explorer, 2005 (Version 3.0): *SA Explorer* [CD],Municipal Demarcation Board, Pretoria, Republic of South Africa.

Salter, J., 1999: A risk management approach to disaster management, in Ingelton, J. (ed.), *Natural disaster management: A presentation to commemorate the International Decade for Natural Disaster Reduction 1990-2000,* Tudor Rose, Leicester, 111-113.

Schmidlin, T., King, P.S., Hammer, B.O. and Ono, Y: 1998: *Risk factors for death in the 22-23 February 1998 Florida Tornadoes*, Quick Response Report No. 106, Natural Hazards Centre, University of Colorado, Boulder, United States of America.

Schmidlin, T.W. and Ono, Y., 1996: *Tornadoes in the districts of Jamalpur and Tangail in Bangladesh*, [online], available:http://www.Colorado.EDU/hazards/qr/qr90.html[14/11/2000].

Schulze, B.R., 1965: Hail and thunderstorm frequency in South Africa, *Notos,* 14, 67-71.

Schulze, R.E., 1997: *South African atlas of agrohydrology and climatology,* Report TT82/96Water Research Commission, Pretoria, Republic of South Africa.

Schuster, S.S., Blong, R.J., Speer, M.S. and Leigh, R.J., 2005: Climatology of hailstorms in New South Wales (Australia) and implication for estimating property damage with radar, conference presentation, 5th Annual Meeting of the European Meteorological Society, Utrecht, Netherlands.

Setvak, M. and Snow, J.T., 2003: Preface, *Atmospheric Research,* 67-68, 1-2.

Setvak, M., Salek, M. and Munzar, J., 2003: Tornadoes within the Czech Republic: from early medieval chronicles to the "internet society," *Atmospheric Research,* 67-68, 589-605.

Simon, D. and Ramutsindela, M., 2000: Political geographies of change in southern Africa, in Fox, R. and Rowntree, K. (eds.), *The Geography of South Africa in a Changing World,* Oxford University Press Southern Africa, Cape Town, 89-113.

Smith, K., 1992: *Environmental Hazards: Assessing risk and reducing disaster,* Routledge, London.

Smith, K., 1996: *Environmental Hazards: Assessing risk and reducing disaster, 2nd Edition,* Routledge, London.

Smith, K., 1997: Climatic Extremes as a Hazard to Humans, in Thompson, R.D. and Perry, A. (eds.), *Applied Climatology: Principles and Practice,* Routledge, London, 304-316.

Snow, J.T., 2001: Editorial, *Atmospheric Research,* 56, 1-4, 1-2.

Snow, J.T. and Wyatt, A.L., 1997: Back to basics: the tornado, nature's most violent wind, Part 1: Worldwide occurrence and categorisation, *Weather,* 52, 10, 298-304.

South African Press Association-Agency France Press (Sapa-AFP), 2006: Raging floods hit rural communities of East Africa, *Weekend Post,* September 2, 2006, p.7.

South African Weather Service, 1991: CAELUM*: A history of notable weather events in South Africa: 1500-1990,* South African Weather Service, Pretoria, Republic of South Africa.

South African Weather Service, 1998: CAELUM: *Notable weather and weather-related events in South Africa:* 1991-1998, South African Weather Service, Pretoria, Republic of South Africa.

South African Weather Service, 2004a: CAELUM, electronic version, *Notable weather and weather-related events in South Africa:* 1961-2004 (geocoded), South African Weather Service, Pretoria, Republic of South Africa.

South African Weather Service, 2004b: *Weather myths, beliefs and legends,* South African Weather Service, Pretoria, Republic of South Africa.

South African Weather Service, 2006: Lightning ground stroke density for December 2005-March 2006, unpublished map, South African Weather Service, Pretoria, Republic of South Africa.

Statistics South Africa, 2002: *South African statistics,* Statistics South Africa, Pretoria, Republic of South Africa.

Statistics South Africa, 2003: *Census 2001: Census in brief,* Statistics South Africa, Pretoria, Republic of South Africa.

Statistics South Africa, 2006: *2001 Census data,* [online], available: http://www.statssa.gov.za/census01/html/C2001Interactive.asp [12/04/06].

Stensrud, D.J., 2001: Using short-range forecasts for predicting severe weather events, *Atmospheric Research,* 56, 1-4, 3-17.

Strydom, M. and Braune, M.J, 2005: *Innovative and practical use of Geographic Information System technology to quantify and prioritise hazards and risks for pro-active disaster management planning,* conference presentation, Disaster Management Institute of Southern Africa Annual Conference, Hartenbos, Republic of South Africa.

Taljaard, J.J., 1958: *South African air-masses: Their properties, movement and associated weather,* unpublished PhD thesis, University of the Witwatersrand, Johannesburg, Republic of South Africa.

Tew, M., 2006: Enhanced Fujita Scale, NWS Partners Meeting.

Thywissen, K., 2006: Components of risk: A comparative glossary, *Studies of the University: Research, Counsel, Education,* No.2 (2006), United Nations University: Institute for Environment and Human Security, Bonn, Germany.

Tierney, K.J., Lindell, M.K. and Perry, R.W., 2001: *Facing the unexpected: Disaster preparedness and response in the United States,* Joseph Henry Press, Washington D.C.

Tobin, G.A. and Montz, B.E., 1997: *Natural hazards: Explanation and integration,* Guilford, New York.

Tobin, G.A. and Montz, B.E., 2004: Natural hazards and technology: Vulnerability, risk and community response in hazardous environments, in Brunn, S.D., Cutter, S.L. and Harrington, J.W. (eds.), *Geography and Technology,* Kluwer Academic Publishers, Dordrecht, 547-570.

Tobin, G.A., Whiteford, L.M. and Laspina, C., 2005: *Perception, social support and chronic exposure to hazards: human health and community well-being, Technical Report,* The Global Center for Disaster Management and Humanitarian Action, University of South Florida, Tampa, Florida.

Trapp, R.J., Atkins, N.T., Fuelberg, H.T., La Due, J.G., Pence, K.J., Smith, T.L. and Stumpf, G.J., 2001: Meeting summary: 20th Conference on severe local storms, *Bulletin of the American Meteorological Society,* 82, 10, 2251-2258.

Twigg, J., 2001: *Sustainable livelihoods and vulnerability to disasters, Disaster Management Working Paper 2/2001*, Benfield Greig Hazard Research Centre, London, United Kingdom.

Tyrrell, J., 2001: Tornadoes in Ireland: an historical and empirical approach, *Atmospheric Research,* 56, 1-4, 281-290.

Tyson, P.D. and Preston-Whyte, R.A., 2000: *The weather and climate of Southern Africa,* Oxford University Press Southern Africa, Cape Town.

United Nations Development Programme, 2004: *Reducing disaster risk: A challenge for development,* United Nations Development Programme, New York, United States of America.

University of Illinois, no date: *Types of thunderstorms*, [online], available: http//ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/svr/type/home.rxml [10/05/06].

Van Heerden, J. and Hurry, L., 1992: *Southern Africa's weather patterns: An introductory guide,* Arcadia Books, Cape Town.

Van Niekerk, H. and Sampson, G., 1999: *Hell Season or par for the Course: Tornadoes over the Eastern Cape 1998/99 Season*, Internal Report Number OB/17, South African Weather Bureau, Pretoria, Republic of South Africa.

Vellinga, P. and van Verseveld, W.J., 2000: *Climate change and extreme weather events,* Vrije Universiteit Amsterdam, Institute for Environmental Studies and WWF-World Wide Fund for Nature, Gland, Switzerland.

Viljoen, F., 1987-1988: *List of extreme weather events*, South Africa Weather Bureau, Pretoria, Republic of South Africa.

Vincent, K., 2004: *Creating an index of social vulnerability to climate change for Africa,* Working Paper No. 56, Tyndall Centre for Climate Change Research and Centre for Social and Economic Research on the Global Environment, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom.

Visser, P.J.M., 1999: *The use of volumetric scanned weather radar reflectivities for the identification of convective storm characteristics,* unpublished Masters thesis, University of Pretoria, Republic of South Africa.

Visser, P.J.M., 2001: The Storm-Structure-Severity Method for the identification of convective storm characteristics with conventional weather radar, *Meteorological Applications,* 8, 1-10.

Visser, P.J.M., 2006: *Meteorological observations: The need for more!* conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Vitart, F., 2006: *Forecasting techniques,* conference presentation, International Conference on the Application of Meteorological Extremes, Pretoria, Republic of South Africa.

Vogel, C., 1991: *The impact of extreme drought events*, unpublished report, HSRC Human Needs and Environment Programme, Johannesburg, Republic of South Africa.

Vogel, C., 1992: The South African environment: horizons for integrating physical and human geography, in Rogerson, C. and McCarthy, J. (eds.), *Geography in a Changing South Africa: Progress and Prospects,* Oxford University Press, Cape Town, 173-185.

Vogel, C., 1994: Human response to the environment, in Binns, J. A. (ed.), *People and the environment,* London, Wiley, 249-256.

Vogel, C., 1998a: *Paper on disaster management for the poverty and inequality report South Africa,* University of the Witwatersrand, Johannesburg, Republic of South Africa.

Vogel, C., 1998b: Disaster management in South Africa, *South African Journal of Science,* 94, 3, 98-100.

Von Kotze, A., 1999a: A new concept of risk, in Holloway, A. (ed.), *Risk, sustainable development and disasters: Southern perspectives,* Periperi Publications, University of Cape Town, Republic of South Africa, 33-40.

Von Kotze, A., 1999b: Re-orienting disaster management training, in Ingelton, J. (ed.), *Natural disaster management: A presentation to commemorate the International Decade for Natural Disaster Reduction 1990-2000,* Tudor Rose, Leicester, 148-150.

Wadge, G., Wislocki, A., Pearson, E.J. and Whittow, J.B., 1993: Mapping natural hazards with spatial modelling systems, in Mather, P.M. (ed.), *Geographic information handling – Research and applications,* John Wiley and Sons ltd, Chichester, 239-250.

Walter, J., (ed.), 2005: *World disasters report: focus on information in disasters,* International Federation of Red Cross and Red Crescent Societies, Geneva.

Webb, J.D.C., Elsom, D.M. and Meaden, G.T., 2005: *Severe hailstorms as a climatological hazard in the British Isles,* conference presentation, 5th Annual Meeting of the European Meteorological Society, Utrecht, Netherlands.

Wernly, D., 1994: *The roles of meteorologists and hydrologists in disaster preparedness*, World Meteorological Technical Document, WMO/TD-No.598, Tropical Cyclone Programme, Report No. TCP-34, World Meteorological Organisation, Geneva, Switzerland.

White, G.F. (ed.), 1974: *Natural hazards: Local, national, global,* Oxford University Press, New York.

White, G.F. and Haas, J.E., 1975: *Assessment of research on natural hazards,* MIT Press, Cambridge.

Wisner, B., 1995: Bridging "expert and "local" knowledge for counter-disaster planning in urban South Africa, *GeoJournal,* 37, 3, 335-348.

Wisner, B., Blaikie, P., Cannon, P. and Davis, I., 2004: *Natural hazards, people's vulnerability and disasters, 2nd Edition,* Routledge, London.

Wood, F., 2000: The snake in the sky: Tornadoes in clay and local narrative in the Hogsback-Alice area, *Critical arts journal,* 14, 2, 79-95.

World Meteorological Organization, 2006: *Natural disaster prevention and mitigation - Working together for a safer World,* [online], available: http://wmo.ch/disasters/disasterHazardRelatedDatabases.htm. [31/05/06].

Xe.com, 2006: *XE.com Quick Cross Rates*, [on-line], available: http://www.xe.com [01/11/2006].

Yodmani, S., 2001: *Disaster risk management and vulnerability reduction: Protecting the poor*, workshop presentation, Social Protection Workshop 6: Protecting Communities: Social Funds and Disaster Management, Asian Development Bank, Manila, The Philippines.