Understanding the physical and social environmental determinants of road traffic injury in South Africa

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Abstract

Road traffic injuries (RTIs) are a major public health challenge, accounting for significant injury, economic and psycho-social burden to societies across the world. While decreases are projected for many high-income countries (HICs) over the next decade or so, staggering increases in the burden of mortality and morbidity are forecast for low- and middle-income countries (LMICs). The unique contextual influences on RTIs in LMICs are, however, not well understood. Conceptual frameworks applied mostly to HICs also do not provide adequate recognition of the unique contextual influences of LMICs.

Accordingly, the research in this thesis adopts a predominantly geographical approach to incorporate a large range of physical and social environmental effects, and which are aggregated at different spatial and spatial-temporal scales to understand the contextual influences to road traffic injuries (RTIs) in the South African (S.A) setting. In this regard, four studies are presented; these include: a geographical epidemiology and risk analysis at the district council level and for time, space and population aggregations; an integrated spatial-temporal analysis at the province-week level; a fine-scale geographical analysis at the police area level; and a small area analysis at the suburb level for the city of Durban.

In addition to important effects relating to alcohol and travel exposure, findings have shown most environmental influences on RTIs in S.A to be development-related, including effects relating to social and area deprivation, violence and crime, and rurality. With the exception of rurality, the above effects showed a positive association with the occurrence of RTIs in S.A. The findings have implications for alignment and possible integration of road safety policies and practices with other developmental policies in the country. In addition, this research has shown that geographical approaches may provide a useful analytical framework for understanding the complexity and interacting influences within broader systems-based approaches; and especially those of the contextual environment that are particularly relevant for LMIC settings.

Declaration

The research reported in this thesis is my original work which was carried out in collaboration with others as follows:

Chapter 1 was written by Anesh Sukhai.

Chapter 2 - Anesh Sukhai was the lead author on a paper published as:

> Sukhai, A., Jones, A.P. and Haynes, R., 2009: Epidemiology and risk of road traffic mortality in South Africa, *South African Geographical Journal*, 91(1), 4-15.
>
> Anesh reviewed the literature, undertook the GIS and statistical analyses, and wrote the manuscript. Andy Jones and Robin Haynes provided feedback on the design and analyses for the study, and reviewed drafts of the manuscript.

Chapter 3 - Anesh Sukhai was the lead author on a paper published as:

> Sukhai, A., Jones, A.P., Love, B. and Haynes R., 2010: Temporal variations in road traffic fatalities in South Africa, *Accident Analysis and Prevention,* 43, 421-428.
>
> Anesh reviewed the literature, undertook the GIS and statistical analyses, and wrote the manuscript. Andy Jones and Robin Haynes provided feedback on the design and analyses for the study, and reviewed drafts of the manuscript. Barnaby Love contributed to the study design and provided statistical assistance for refining the statistical models.

Chapter 4 and 5 - Anesh Sukhai was the lead author. He reviewed the literature, undertook the GIS and statistical analyses, and wrote the manuscripts. Andy Jones provided feedback on the design and analyses for the study, and reviewed drafts of the manuscript.

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Chapter 6 was written by Anesh Sukhai.

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Commonly used abbreviations

DALYs	Disability adjusted life years
HICs	High-income countries
LMICs	Low- and middle-income countries
RTCIs	Road traffic crashes and injuries
RTFs	Road traffic fatalities
RTIs	Road traffic injuries
S.A	South Africa
YPLL	Years of potential life lost

Chapter 1

General Introduction

1.1 The road traffic injury problem

Road traffic injuries (RTIs) have been described as one of the largest and most preventable of all modern epidemics (Pless, 2004). Moreover, despite increasing attention and efforts over recent years, RTIs persist as a major public health challenge, accounting for significant injury, health, and economic costs to families and to societies across the world.

Globally, an estimated 1.2 million people are killed and as many as 50 million sustain non-fatal injuries in road traffic crashes each year (Peden et al., 2004). With more than 50% of the global mortality from RTIs occurring among young adults in the economically productive age group between 15-44 years, RTIs contribute more years of potential life lost (YPLL) than does any other cause of death (Peden et al., 2004). In addition to the physical consequences of trauma, disablement and death, victims and families are also predisposed to an array of psychosocial trauma and other health consequences, such as substance abuse from dealing with long-term consequences from factors such as disability and loss of earnings. Typically, RTIs consume between 1-2% of the gross national product of countries. Of concern is that, in the absence of greater commitment and novel approaches to prevention and control, by 2020, forecasts indicate that deaths could increase by 65%, and DALYs to 71.2 million (from 34.3 million) to account for 5.1 % of the global burden of disease (Murray & Lopez, 1996). In terms of rankings, RTIs are predicted to rise from eleventh to the sixth leading cause of death, and from ninth to the third leading cause of disability adjusted life years (DALYs) lost globally.

Low- and middle-income countries (LMICs) will, however, be most affected. The general trend from the 1960s and 1970s until about the start of the 21st century has been a decreasing magnitude in the numbers and rates of fatalities in high-income countries (HICs) such as Australia, the Netherlands, Sweden, the United Kingdom and the United States of America, whilst at the same time, an increasing trend has been evident for many LMICs across the world (Jacobs et al., 2000; Peden et al., 2004). The burden to LMICs is substantial, with these countries accounting for 85% of deaths and 90% of disability adjusted life years (DALYs) lost worldwide (Krug et al, 2000; Peden et al., 2004). The road traffic fatality rates in LMICs are also disproportionately high, being about twice those of HICs (20.2 vs. 12.6 deaths per 100 000 population) (Murray et al., 2001). Forecasts for LMICs are worse. Whilst a general 30% decrease in road traffic deaths is expected for HICs, deaths in LMICs are predicted to increase on average by over 80%. In addition, RTIs are predicted to become the second leading cause of DALYs lost (Murray & Lopez, 1996). LMICs are also less able to shoulder the economic burden from RTIs. The direct costs, estimated to be US$65 billion, typically exceed the developmental assistance received by these countries (Peden et al., 2004). These consequences place a drain on the scarce resources of disadvantaged families, hampers economic development, and further perpetuate poverty.

South Africa (S.A) is no exception from the poor status and projections, and moreover estimates for the country may also be worse than those for LMIC averages. Estimates from the last South African National Burden of Disease Study in 2000 (Bradshaw et al., 2003) show an estimated annual incidence of approximately 18 400 road traffic deaths for the country. These deaths translate to an annual road traffic fatality rate of 43.0 deaths per 100 000 population, which is about twice the average for LMICs and four times the global average (Murray et al., 2001). Further, estimates for 2006 indicate that South Africa spends about R43 billion (NDOT, 2006) or 2.9% of its 2006 GDP (StatsSA, 2007) on the consequences of road traffic crashes.

The causes of road traffic crashes and injuries (RTCIs) are multi-faceted. However, based on the World Report on Road Traffic Injury Prevention (Peden et al., 2004), risk in the road traffic environment may be conceived as a function of four key elements: (1) Exposure, relating to the amount of travel undertaken; (2) The probability of a crash occurring, such as from driving under the influence of alcohol; (3) The probability of injury, such as from the usage of occupant restraints; and (4) The severity of injury, that may be influenced by the timeliness of emergency responses. Of these influences, exposure to traffic has been shown to be a particularly important contributor to RTCIs. For example, Fridstrøm et al. (1995) showed traffic-related exposure to account for 70% of the systematic variation in injury accidents and 50% of fatal accident variations in accident counts among four Nordic countries.

The growing number of motor vehicles in many parts of the world is also claimed to be one of the leading factors of the increasing burden of RTCIs (Peden et al., 2004). In this regard, a large body of research has demonstrated the contributory influences of traffic volume to road crashes (for example, Lassarre, 1986; Golias, 1992; Nicholson & Wong, 1993). However, in the face of increasing levels of motorisation, many HICs have shown a general decreasing trend in RTCIs. This has been attributed to significant and responsive investment in research, regulations and other prevention and control strategies. Key efforts have focussed on seat-belt use, vehicle crash protection, traffic-calming strategies, and traffic law enforcement (Peden et al., 2004; Lamm et al., 1985). It follows then, that LMICs in general have not been successful with implementing the necessary infrastructure and other safety measures in the face of increasing levels of motorisation. An obvious reason for this gap is a lack of resources for road safety initiatives, which may be absolute and dependent on the levels of economic development in countries, or relative to other competing health priorities. In addition to the heightened epidemic of HIV/AIDS that is particularly pronounced in LMICs, large populations in these countries are generally at risk of a triple threat of infectious diseases from overcrowded conditions, non-communicable diseases as a result of unhealthy urban lifestyles, and injury-related disorders (WHO and UN-HABITAT, 2010), and, as described for the S.A setting, also a 'quadruple' burden that includes perinatal and maternal disorders (Mayosi et al., 2009).

In addition, transport patterns and traffic mixes are fundamentally different in LMICs compared with HICs. Victims of RTIs in LMICs are more likely to be vulnerable road users, including pedestrians and other non-motorised vehicle users; also for whom little research has generally been conducted (Peden et al., 2004). Unsafe traffic-related infrastructure and public transportation systems also contribute to an increased exposure to crashes and injuries in these settings (Odero et al., 1997). Spatial disparities in many LMICs, often due to policies and practices that systematically disadvantage certain populations such as with colonisation and apartheid in the case of South Africa (Coovadia et al., 2009; Seedat et al., 2009), also contribute to risk within the traffic system. Such policies and practices of disadvantage often manifest as increased exposure and risk to vulnerable populations, which may be from the need to travel greater distances to work and services, and in some settings such as in South Africa, many migrant workers are at an increased risk from needing to travel several times a year from their traditional homes in remote rural areas to secondary homes in urban areas for employment.

In recognition of the substantial and growing global burden of RTIs, organisations such as the World Health Organisation, the World Bank, and the United Nations have in recent years been leading on initiatives to address RTCIs. The landmark “World Report on Road Traffic Injury Prevention” (Peden et al., 2004) was jointly released by the WHO and World Bank in 2004. The report presented a comprehensive overview of what is known about the epidemiology, risks, and strategies for preventing and lessening the impact of road crashes across the world. More recently in 2010, following a United Nations resolution, the UN General Assembly proclaimed the period 2011-2020 as the Decade of Action for Road Safety (WHO, 2011). The strategy aims to stabilise the growing burden, and then reduce the forecasted level of RTIs during the 10-year period, and calls on UN member states, international agencies, civil society organisations, businesses and community leaders to promote efforts to curb rising traffic injuries and fatalities. The strategy includes five “pillars” of activities focussed on building capacity for road safety management, improving the safety of traffic-related infrastructure, further developing the safety of vehicles, enhancing the behaviour of road users, and improving post-crash care. An ambitious target has been set to save 5 million lives and 50 million serious injuries over the 10-year period. Whilst formal global progress updates are not available, indications from South Africa are that not much progress has been made in the country, as evidenced by the persistently high number of fatalities for the 2010-2011 period (RTMC, 2011) as well as for the recent 2012/2013 Christmas festive season, where unprecedented levels in road traffic fatalities (RTFs) have been reported (Mposo & Cox, 2013).

An early task of the thesis was to review a range of models or frameworks that could be used to guide the research. These frameworks focussed primarily on understanding the occurrence of RTIs, but also included those relating to environmental influences on health, for the purpose of understanding the role of the contextual environment. These two broad categories of frameworks are discussed in the following two sections.

1.2 Conceptual and analytical frameworks for understanding the occurrence of RTIs

Beyond models that focus on individual level functioning and resultant behaviour such as from the medical or psychological paradigms, from a public health perspective, three major conceptual models have provided the basis to the scientific enquiry of injury prevention and control, including RTCIs. These models include the Public Health Model, the Haddon's Matrix, and the Systems Approach to road safety. In comparison, whilst the Haddon's Framework tends to be equally useful for understanding causality and for designing intervention strategies, the public health and systems-oriented approaches tend to be more intervention-focussed.

1.2.1 Public Health Model

The Association of Schools of Public Health in the United States defines public health as "the science of protecting and improving the health of communities through education, promotion of healthy lifestyles, and research into disease and injury prevention" (Association of Schools of Public Health, 2012). Accordingly, in contrast to a narrow focus on individuals such as with clinical medicine, public health is concerned with addressing large-scale population-based health priorities, RTIs being one example. A key principle of public health strategies is the use of multi-disciplinary perspectives, whereby knowledge from an array of disciplines including medicine, biomechanics, engineering, epidemiology, sociology, criminology, education, and other disciplines (Peden et al., 2004).

The Public Health Approach or Model has been advocated as a scientific method for addressing injury using public health principles (CDC, 2008). The model comprises a spectrum of 4 core components including: (1) Defining and monitoring a problem, (2) Identifying its risk and protective factors; (3) Developing and testing of prevention strategies; and (4) Assuring widespread adoption of prevention strategies. The model is cyclical in that there is a feedback loop from the fourth to the first phase to allow for refinement of intervention strategies.

Kress et al. (2012) recently highlighted the top 20 violence and injury practice innovations that embody public health principles, and that contributed to declines in injury over the past 20 years, especially in the United States. Seven of these strategies focussed on road safety, and included, for example, interventions targeting alcohol (0.08 blood alcohol concentration laws, sobriety checkpoints, and ignition interlocks) and vehicle restraints (occupant airbags and seatbelts, and child passenger restraint seats). Whilst these strategies illustrate how prevention practices may be conceptualised and delivered, they also emphasise the important role that public health has and continues to play in the field of road safety.

The public health principles and model are, however, particularly focussed on interventions, and do not offer a systematic and detailed framework for understanding the various contributory factors of risk in the road traffic system. Their merit does, however, lie in providing a macro-level framework to prioritise and guide actions on public health priorities, such as RTIs.

1.2.2 Haddon's Framework & Epidemiological Model

In 1970, William Haddon Jr published his seminal editorial "On the escape of tigers: an ecological note" (Haddon, 1970), the ideas of which have been instrumental in shaping the science of injury prevention. The basis of his thesis was that the transfer of energy was the cause of injuries, and as such a data-driven, systematic approach was required for minimising this transfer, and for the prevention of injuries. In this regard, Haddon developed a conceptual model comprising a matrix that identifies risk factors in relation to the person, vehicle and environment; during the pre-crash, crash and post-crash time phases of a crash event. The Haddon's Framework extended previous ideas of the Epidemiological Model, proposed for injury research by Gordon (1949). In this model, the general understanding on disease causation was applied to injuries, where the person, vehicle and environment elements were likened to the so-called epidemiological triad of the host, vector, and environment, respectively. Gordon (1949) also put forward the idea that, as in diseases, injuries were characterised by spatial and temporal variations. Prior to this, injury prevention was largely considered to be inevitable events, and outside the realm of scientific inquiry (Sleet et al., 2011).

The nine-cell matrix of Haddon's Framework (with the temporal dimension as 3 rows, and the epidemiological triad as 3 columns) provides a systematic and comprehensive time and place focus, rendering it especially suited for studying the occurrence of RTIs. Indeed, the model has been used widely for understanding and addressing behavioural, road-related and vehicle-related factors in RTIs by examining each of the cells of the matrix (Peden et al., 2004; Muhlrad & Lassarre, 2005). As an illustration of its application, the matrix may identify a person-related factor in the pre-crash phase to be impairment from excessive alcohol consumption; a vehicle-related factor in the crash phase to be a lack of adequate occupant restraints; and an environment-related factor in the post-crash phase to be delayed response by emergency services. Of note is that Haddon considered both the physical and socio-cultural environments in his model.

In addition to the original conceptualisation, some variations to the model, especially to facilitate its application for research translation have also been proposed. These variations include the addition of a third dimension comprising "value criteria" to facilitate its use for decision-making on choice of countermeasures (Runyan, 2008), in combination with the Public Health Approach (described earlier) to create a 3-dimensional model (Lett et al, 2002); and inclusion of a spectrum of six interrelated action levels that are necessary for an effective prevention campaign (Cohen & Swift, 1999).

The major contribution of the Haddon's Matrix is that it provides a systematic and comprehensive tool with which to understand and to address the occurrence of RTCIs. It focuses on both injury prevention and injury control, and considers all components of the road traffic system. Prior to the adoption of Haddon's Matrix, analyses of the road user, vehicle and environment were treated largely as separate entities. The major criticism, however, is that the framework does not consider the interactions between the various components of the system that contribute to risk and adverse outcomes. For example, while excessive speed may be the main cause attributed to a fatal injury crash where a car veers of the road, there may be other underlying environmental causes such as the lack of protective crash barriers on the roadway that may need to be considered.

1.2.3 Systems Approach to road safety

The Systems Approach builds on the Haddon's Framework, and addresses its key shortcoming around the independent treatment of the various components of the matrix. Within this approach, greater depth is also afforded to understanding the occurrence of RTCIs, whereby the various components of the traffic system are seen to be interacting and to be dynamic in nature. In having the system treated as a whole, the multiplicity of factors comprising direct as well as indirect contributors are considered, using a multidisciplinary approach. From an intervention perspective, a key principle of the Systems Approach is to compensate for human vulnerability and fallibility by encouraging a shared responsibility for safety among the various users of the traffic system; a large responsibility is placed on professionals that create the road systems (Peden et al., 2004; Muhlrad & Lassarre, 2005). The Vision Zero strategy in Sweden and the Sustainable Safety Programme in the Netherlands provide good practice examples for the implementation of Systems Approaches for road safety. Vision Zero was developed in Sweden in 1997, and, as the name suggests, the strategy has the ultimate goal of zero fatalities or severe injuries from road traffic crashes (Johansson, 2009). The approach is based on four elements: (1) Ethics, where health is prioritized over mobility; (2) Shared responsibility for safety by users and developers of the system; (3) A philosophy of safety that accommodates human error by keeping energy within the system below critical levels of human tolerance; and (4) Creating mechanisms for change, such as through setting safety performance standards for the various parts of the road traffic system, and obtaining buy-in from relevant role players. Examples of key intervention strategies include scaling up on speed control, by encouraging local authorities to implement 30 km/h zones; and installation of crash-protective central barriers on single-carriageway rural roads. The Sustainable Safety strategy was launched in the Netherlands in the 1998 and shares many of the generic principles with that of Vision Zero. The aim is to prevent fatal and serious crashes, and where not possible, to eliminate as far as possible, the risk of severe injury. The key focus of the strategy is on speed management through re-engineering of road networks, and especially on converting a maximum number of urban roads to a “residential” function, with the maximum speed limit of 30 km/h (Wegman & Elsenaar 1997).

The adoption of systems approaches have in general been shown to be effective in reducing deaths and serious injuries from road traffic crashes (Peden et al., 2004; Ogden, 1996). Both Vision Zero and Sustainable Safety are long-term strategies; however, preliminary indications of effectiveness are good. More impressive, is that substantial reductions have been achieved in the face of these HICs being among those with the lowest road traffic fatality rates in the world. With Vision Zero in Sweden, over a 10-year period since implementation, there was an overall reduction in the fatality rate from 6 to 4.7 deaths per 100 000 population (Johansson, 2009). In addition, an 80% reduction in fatalities was achieved for roads designed with median barriers, and for streets redesigned with a 30 km/h speed limit. In the Netherlands, an overall 30% reduction in fatalities was found during the period from 1998-2007; this was attributed to the implementation of the comprehensive package of measures based on the Sustainable Safety vision (Weijermars & Van Schagen, 2009).

Despite its merits and successes, however, there have been concerns raised that the required restrictions placed on personal mobility are unacceptable in societies that are highly mobile, and that the targets set by the strategy may also be unrealistic and difficult to achieve (for example: Karyd, 2001). A further concern is its suitability for LMICs, especially because funding will need to be diverted from other priorities for capital intensive initiatives such as upgrades to the transportation infrastructure. In this regard, Elvik (1999) showed the possibility of an increase in general mortality as a result of having fewer resources to control other causes of death. Based on a loss of income of between 3.8–47.5 million US dollars that induces an additional death, Elvik modelled the implementation of the Vision Zero strategy in Norway, and estimated that, with implementing the full programme, the number of traffic deaths could be reduced from about 300 to about 90 per year, but that the implementation could also result in a net increase of about 1145 deaths from all causes per year.

1.2.4 Appraisal of frameworks for road safety research

System-based approaches are largely untested in LMICs and thus, their full adoption in these settings may not be entirely relevant. Particularly prohibitive are the large costs associated with the range of infrastructural measures typically advocated, and also that the role of unique environmental influences tend to be under-recognised. However, based on the Systems Approach, the recognition of the interaction and complexity in the occurrence of RTCIs, which is also consistent also with the idea of a 'web of injury causation' (Robertson, 1998), is critical for advancing and understanding the occurrence of RTCIs in these settings. Commentators such as McClure et al. (2010) and Rivara (2002) have also argued that current research and practice tends to be dominated by epidemiological methods focussed on proximal or the more directly contributing risk factors (Rothman, 1986). Similarly, in terms of road RTCIs, there is the dominant view that human error and hence road users are the main cause of road traffic crashes (Peden et al., 2004; Treat et al., 1977; Sabey and Taylor, 1980). With such a view, the focus of strategies tends to be focussed on modifying road user behaviour (Zein & Navin, 2003; Peden et al., 2004; Mackay & Tiwari, 2005). That more than 90% of crashes are often attributed in police reports to driver error may also be an important reason for such simplistic representations of road safety (Zein & Navin, 2003; Johansson, 2009). It follows then that a greater focus and investment is needed on understanding the context of the large burden of RTCIs in LMICs, in order that innovative and contextually-relevant strategies are available for addressing the aforementioned large burdens in these countries.

1.3 Conceptual and analytical frameworks for understanding environmental influences

1.3.1 Conceptualisations of place and space

Prior to the 1990s, area-based research has largely been dominated by the principle of individualism. Individualism, from a geographical perspective, claims that the differences in health outcomes observed between areas are due to the characteristics of the individuals that live in them, the effects of which are referred to as compositional (Macintyre, 2007; Macintyre et al., 2002). Since the 1990s however, there has been a growing interest in the role of the physical and social environment on health outcomes (Cummins et al., 2007); Diez-Roux, 2001). For example, the “Social Accident” model, proposed by Factor et al. (2007) places a particular focus on social and cultural influences on road safety. The model is based mainly on sociological theory, and suggests that social groups have different cultural characteristics, and these differences allow for drivers in different groups to interpret situations differently, to responding differently, especially in terms of engaging in high-risk driving behaviour, and to show different involvement in crashes and injuries. Conventional research on environmental influences in health has tended to focus on contextual and compositional effects, with more recent research focussing on broader systems-orientated approaches, both of which are discussed below.

Within place-based research, population risk has traditionally been viewed as being a combination of compositional effects that result from an aggregation of individual risk factors, as well as contextual effects that are external to individuals and that tend to affect groups of people in particular settings (Curtis & Jones, 1998). However, research has pointed to the complex relationships between people and places, which have also resulted in blurring in the context-composition divide (Cummins et al., 2007). Accordingly, Cummins et al. (2007) argue against the false dualism of context and composition owing to the “mutually reinforcing and reciprocal relationship between people and place” (p.1835). In addition, research has also generally advanced from delineating the contributions of area and individual level effects, to understanding the plausible causal pathways by which social and physical environments may affect health outcomes (Macintyre, 2007). Such research, focussed on disentangling these effects, has also been characterised by narrow conceptualisations of space; hence these narrow conceptualisations have generally resulted in an underestimation of the role of contextual effects (Cummins et al., 2007), as evidenced by a relatively small proportion of total variability in outcomes between areas being attributed to place level effects (Jones & Duncan, 1995; Boyle & Wilms, 1999; Ecob, 1996).

With environmental health research, in contrast to a narrow focus on the context-composition divide, and consistent with principles from a broader systems-orientated approach, geographical approaches may allow for a very relevant interdisciplinary framework by which to understand the wide range of influences on the occurrence of RTIs. It has, however, long been argued by Whitelegg (1987) and others, that research focussed on individual driving behaviour, on vehicle safety design, and even on crash-related factors has reached a state of diminishing return. Accordingly, geographical approaches are particularly relevant in providing a conceptual and analytical platform on which to integrate the influences from both the social and physical environments, and their interacting effects within a single framework. Such environmental effects may for example include land use, road network characteristics and weather-related measures for the natural environment, as well as socio-economic, travel exposure, and public intervention measures for the social environment. In contrast to broader geographical approaches, the Social Accident model, (Factor et al., 2007) for example, provides an understanding of one component of the environment, which is the socio-cultural environment; it thus fails to capture the broader interacting influences of the contextual environment as a whole. Further, aggregated compositional factors and the interacting effects of compositional and contextual influences may be missed with research focussed at the individual level, referred to as the atomistic fallacy (Curtis & Jones, 1998). Geographical approaches also allow for a broader interpretation of compositional effects where the aggregated effect of individual characteristics is seen to be more than simply the sum of its parts (Curtis & Jones, 1998). This complexity and recognition of the totality of factors that operate in combination to bring about an injury event is also expounded on within the Ecological Model of Injury Causation (Susser & Susser, 1996a; Susser & Susser, 1996b); ideas are put forward in the Complexity Theory by Gatrell (2005).

System-wide geographical studies on RTIs have mostly been undertaken in HIC settings, including countries of Europe (Van Beeck et al., 1991; Noland & Quddus, 2004; La Torre et al., 2007; Rivas-Ruiz et al., 2007; Jones et al., 2008; Erdogan, 2009; Spoerri et al., 2011), and in the United States (Aguero-Valverde & Jovanis, 2006). These studies have tended to incorporate a range of spatially defined explanatory variables, and have demonstrated the important effects of traffic and travel exposure, high-risk driving behaviour, especially driving under the influence of alcohol; socio-economic deprivation, and rurality, as predictors of RTFs.

Of particular relevance to the occurrence of RTIs in LMIC settings are findings on rurality and deprivation, especially owing to the large extent of urbanisation and associated poverty-related conditions (WHO, 2010).

In HICs, several studies have shown rurality, commonly measured using area-based population density to be inversely related to RTFs, suggesting higher levels of fatalities in rural areas (Thouez et al., 1991; Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011). Rurality, however, is a spatial description and does not reflect the processes behind these effects. However, in these countries, the higher burden of RTFs in rural areas has been shown to associated with relatively higher levels of risky driving behaviour such as drinking and driving, excessive driving speeds and non-wearing of seatbelts (Besag & Newell, 1991; Dumbaugh & Rae, 2009; Strine et al., 2010) as well as poorer injury outcomes owing to inadequate access to quality pre-hospital and advanced in-hospital trauma care (Baker et al., 1987; Van Beeck et al., 1991).

The effects of rurality on RTIs and the processes that may drive them are not clear for LMICs. Such understandings are critical, because it is these settings that are particularly vulnerable to the challenges of rapid urbanisation, which is expected to worsen, because urban populations in LMICs are forecast to double over the period 2000 to 2030 (WHO, 2010). In addition to high levels of poverty-related conditions that tend to accompany rapid and unplanned urbanisation in these settings, there are traffic-related challenges around inadequate traffic facilities for migrants, which are compounded by many of them being relatively unfamiliar with modernised traffic systems.

While poverty-related conditions tend to accompany rapid and uncontrolled urbanisation, the linkages between these effects have not been explored in any detail. Further, while the role of socio-economic deprivation on RTIs is well documented, the role of area level deprivation, which is particular to LMICs, has not been adequately researched. In terms of socio-economic deprivation, lower socio-economic status, such as from income and education deprivation, for example, has been shown to be associated with a generally higher probability of accident involvement (Borrell et al., 2005; Rivas-Ruiz et al., 2007; Spoerri et al., 2011; Factor et al., 2008).

1.3.2 Analytical considerations with environmental influences

Following the complexity in understanding environmental influences on RTIs, a large range of variables, proxying effects in various contexts have been incorporated, using various conceptual and empirical models to accommodate variations in outcomes and explanatory measures. In addition, factors that affect RTIs differ both in space and time, which allows for the analysis of counts of RTIs within cross-sectional and longitudinal designs or combinations of them, such as with panel designs. Empirical models commonly adopted to examine the counts of RTIs include multi-variable linear regression models with negative binomial specifications to account for over-dispersion (for example, Jones et al., 2008; Noland & Quddus, 2005), as well as more advanced Bayesian spatial models that allow for Bayesian inferential and probability analyses (for example, Aguero-Valverde & Jovanis, 2006, Spoerri et al., 2011).

Of particular interest for understanding and modelling the complexity with the occurrence of RTIs, especially with the role of environmental influences, has been the application of multilevel modelling frameworks to analyses. Multilevel models are particularly suited to clustered data, and are commonly used to decompose area or group characteristics from characteristics of individuals living in different areas (Diez-Roux, 2001; Kearns & Moon, 2002). In addition to assessing the variation at the different levels, such models allow for a more reliable estimation of standard errors of estimates, and hence are less likely to generate spurious statistically significant findings (Goldstein, 1995; Maas & Hox, 2004). The application of multilevel modelling frameworks to understand the broader contextual environment of RTIs is scanty, although this may be particularly relevant for studying the role of contextual influences on RTIs. Their utility has, however, been demonstrated for understanding individual and area risk factors for RTFs in South Korea, for example (Park et al., 2010), as well for understanding the hierarchical effects at the casualty, accident and area level for seriously and fatally injured casualties in Norway, for example (Jones & Jørgensen, 2003).

1.4 Research problem, rationale and focus of thesis

Area-based studies that have examined RTCIs range from very localised studies undertaken for roads and intersections (Miranda-Moreno et al., 2007; El-Basyouny and Sayed, 2011), to neighbourhoods (Morency et al., 2012; Chini et al., 2009); to large geographical units across a country such as regions of Italy (La Torre et al., 2007) or provinces of Spain (Rivas-Ruiz et al., 2007). Whilst such studies have yielded important methodologies and findings such as on the identification of “black spots” (Miranda-Moreno et al., 2007), or the identification of predictors using geographical determinant-based analyses (La Torre et al., 2007; Rivas-Ruiz et al., 2007), they have largely not been effective in capturing the depth of social and physical environmental influences that may underpin observed variations in outcomes from a broader systems perspective, especially those particular to LMIC settings. Consequently, generic conceptual frameworks may be incomplete and inadequate for addressing RTIs in LMICs, and may need to be extended through new insights on the role of context so as to be more relevant for such settings.

Considering the huge and increasing burden of RTIs in LMICs, there is a critical need for novel evidence-based approaches to inform relevant policy and intervention responses for addressing RTIs. Without adequate responses, burden of disease projections indicate that LMICs will need to shoulder a staggering increase in the burden of RTIs (Peden et al., 2004). With the cost of RTIs exceeding the total amount of development assistance they receive, RTIs also pose a significant developmental challenge to LMICs (Peden et al. 2004). The paucity of analytical research and understanding on the environmental influences on RTIs may also explain, in part, the predominant road user approach that tends to prevail for policy and practice in many LMICs.

Accordingly, this thesis seeks to broaden our understanding of the contextual physical and social environmental determinants of RTIs, particularly in the South African context where there is currently an absence of systematic analyses on the determinants of RTIs. In addition, the research also seeks to contribute South African and LMIC perspectives to the global body of research on RTIs, and in particular the growing body of geographical determinant-based research. A predominantly geographical approach is used within the thesis to understand the role of environmental context on RTIs. In addition, a wide range of variables, with some being more particular to LMICs, such as varying measures of deprivation and rurality, and focussing on differing road users, are integrated within broad analytical frameworks. Various geographical scales, as well as space-time variations, are considered, to account for those influences that may be better captured at a particular scale or space-time variability.

The thesis is presented as a series of four papers and as such, detail on the case and variable selection, as well as the methods used are provided in their relevant chapters. Figure 1.1 shows the structure of the thesis, used as the broad framework for understanding the environmental determinants of RTIs in South Africa. These components are described briefly below.

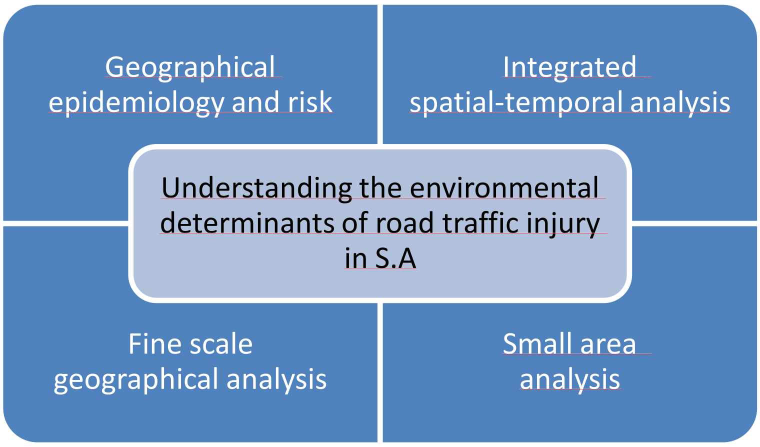

Figure 1.1: Thesis structure

Following this introduction, Chapter 2 addresses the paucity of South African data on the geographical epidemiology and risk of RTFs using national data from 2002-2006. Demographic, road user, temporal and seasonal characteristics are examined, as are a number of measures relating to the geography of road traffic fatality risk, which has not been previously examined for South Africa. Two different exposure-based rates relating to population counts and vehicle ownership are calculated in order to quantify and explicate traffic fatality risk. Geographical analysis is undertaken at the District Council (DC) municipality census level, and four area-based measures of rurality are computed and used to compare the exposure-based rates for various road user groups. The rurality measures used include percentage rural population, average population size, crude population density and person-weighted population density. The implications of these findings in order to understanding the epidemiology, risk and geography of RTFs in the country are discussed. Future directions for research are also discussed.

In Chapter 3, the factors that explain temporal variations in RTFs in S.A are examined. An integrated spatial-temporal framework is used to incorporate time-series data for 9 provinces and 260 weeks from 2002-2006, yielding 2340 province-week observations. A total of twenty variables, most of which show variations by space and time, are considered; these include traffic exposure measures, such as volume of fuel sales, weather conditions, such as average daily rainfall, and various types of holidays such as for schools and the general public. Non-linear autoregression exogenous (NARX) regression models are fitted to explain the variations in RTFs and to assess the degree to which the variations between the provinces are associated with the temporal variations in risk factors. A multilevel formulation is used to explicitly model the variations at both the spatial and time dimensions. The implications for future research and for interventions are also discussed.

In Chapter 4, following an identified research need from the previous analyses, a detailed fine-scale geographical analysis is undertaken to investigate the physical and social environmental correlates of spatial variations in RTFs in S.A. The research is based on a cross-sectional geographical design and for 993 police areas as the principal geographical level of analysis. A total of 72 variables, classified by nine risk categories are considered, and include measures relating to violence and crime, risk exposure, driver behaviour, characteristics of the resident population, physical characteristics of the police areas, and climate. Several dimensions of factors that are considered pertinent to LMICs including in S.A are considered, incorporating measures of deprivation, rurality, and travel exposure. However, attention is given to exploring the association between road traffic, and violence- and crime-related injuries due to the particularly high public health impact of both injury types in the S.A context. Multilevel negative binomial regression models are fitted to examine the variations in the counts of RTFs between the police areas. The implications for policy, practice, and future research are also discussed.

In Chapter 5, following the compelling effects shown for population density in Chapters 2 and 4, this study uses population density as an organising framework to demonstrate and then decompose the effects of population density on RTIs, by examining the variations and influences of the characteristics of the crashes, as well as measures of socio-economic deprivation by quartiles of population density. In addition, negative binomial regression models were fitted to model the predictors of the road traffic outcomes for the EMA, as well as to explicate some of the effects arising from population density. The research is based on data from 2005-2009 and on a cross-sectional geographical design at the small area suburb level for the eThekwini Metropolitan Area (EMA). The EMA, located in the province of KwaZulu-Natal, is one of eight metropolitan areas in S.A, incorporating the large city of Durban. Whilst the effects of population density and deprivation may be more apparent for small areas within cities and other urban centres, small area analyses of RTIs and risk is of particular importance for the S.A context owing to the added risks from socio-spatial disparities, arising from historical urban planning policies under the apartheid regime. Measures on the nature and circumstances around the crashes include time and day of occurrence, road-surface condition, type of crash, and type of vehicle. For socio-economic deprivation, a range of measures relating to population living in informal shack dwellings, education level, employment, and income are examined. In addition, various levels of injury severity and differing road user groups are considered for this analysis.

Finally, Chapter 6 sets out the conclusions of this work. A summary of the principal findings contributing to understanding the determinants of RTIs in the country is provided. The wider implications and recommendations, strengths and limitations, and avenues for further research are also discussed.

1.5 The South African setting for geographical research on RTIs

Figure 1.2 shows a map of the South African country setting for the research in this thesis, and depicts the country's nine provinces and major cities. Three of the studies in this thesis are country-wide, and the small-area study was undertaken for the City of Durban on the East Coast of the country.

Figure 1.2: Map of South Africa (source: www.cybercapetown.com)

The country covers a land area of 1.2 million square kilometres and is home to some 51.8 million people. The province with the largest land area is the Northern Cape, whilst Gauteng, wherein lies the administrative capital city of Pretoria, is the most populous (S.A Info, 2012). The traffic environment comprises approximately 9.9 million registered vehicles and 9.3 million licensed drivers (RTMC, 2011).

The country, as with many other LMICs is, however, plagued by many developmental challenges, including high levels of poverty and ill-health. The country's quadruple health burden (Mayosi et al., 2009) that includes injuries has largely been attributed to the systematic disadvantaging of certain race groups during the country's apartheid regime (Coovadia et al., 2009; Seedat et al., 2009). Apartheid policies were aimed at segregating the various population groups, in order to preserve white political and economic domination of the country, with black residential areas (also called townships or homelands) created on the outskirts of growing urban areas (Christopher, 1997). Various laws were passed to legalize, institutionalize and maintain this physical separation (Prozzi et al., 2002). Further to the physical separation and laws dictating place of residence and controlling of movement, non-white populations were systematically disadvantaged by under-investment in infrastructure, education, health and other social services and amenities, creating large areas of unemployment and poverty in the country (Patel, 2004;

Prozzi et al., 2002). These policies and practices, whilst not investigated directly in this thesis, provide a background to the manifestation of risk and exposure to RTIs in the country, such as from deprivation, rapid urbanisation and excessive travel. These historical challenges and manifestations, along with a disproportionately high burden of RTIs, provides for the S.A setting being a particularly useful test bed to explore the role of environmental influences on the occurrence of RTIs.

Chapter 2

Epidemiology and risk of road traffic mortality in South Africa

Abstract

In view of the large and increasing road traffic fatality burden in South Africa, this study describes the distribution of the risk of fatal RTIs according to population and rural-urban characteristics in the country, between 2002 and 2006. Two different exposure-based rates relating to population counts and vehicle ownership were calculated to quantify and explicate traffic fatality risk. Demographic, road user and temporal characteristics were examined, as were a number of measures relating to the geography of road traffic fatality risk, which has not been previously examined for South Africa. Geographical analysis was undertaken at the District Council Municipality (DC) census level where four area-based measures of rurality were computed: percentage rural population; average population size (of Main Place census areas within each DC); crude population density; and person-weighted population density. There were substantial variations in risk associated with population, temporal and seasonal characteristics, and measures of rurality. Results showed high rates for the black, male, economically active, and pedestrian groups, and large proportions of cases to have occurred over evenings and weekend hours. The relationship between rurality and traffic fatality risk was found to be non-linear. However, the lowest fatality rates were apparent for highly urban areas. In addition, the vehicle based fatality rate showed to be a better discriminator than the population based fatality rate at differentiating rural-urban fatality levels. The findings provide new insights on the distribution of RTFs in South Africa that should guide intervention strategies targeted at addressing this considerable public health challenge.

2.1 Introduction

Understanding the distribution of the risks of road traffic deaths is fundamental to improving road safety, especially in many LMICs that exhibit a disproportionately higher burden, but have a relative lack of analytical research on their determinants, in comparison with HICs. Of the global burden of RTIs, LMICs experience 85% of all fatalities and account for 90% of all Disability Adjusted Life Years lost (Krug et al., 2000). Globally, RTIs was ranked as the 11^{th} leading cause of death in 2002 (Mathers et al., 2002), but the South African National Burden of Disease Study in 2000 showed these injuries to be the 7^{th} leading single cause of death in the country, accounting for 12% of deaths from all causes (Bradshaw et al., 2003). The national incidence of crashes and fatalities in South Africa has also shown increasing trends. For example, the Road Traffic Management Corporation (RTMC) showed that there were approximately 12 500 fatal crashes and 15 400 fatalities in 2006, increases from 2001 by 42% and 37%, respectively (NDoT, 2007).

Exposure is a significant component of traffic-related risk (Peden et al., 2004) and usually relates to the volume of accident opportunities that a road user encounters in the traffic system (Chapman, 1973; Risk & Shaoul, 1982). Several exposure-based indicators are commonly used to compare traffic-related risk between populations and areas. Despite the inherent limitations to many of these measures, the population-based fatality rate is the preferred indicator for showing the public health impact of crashes in relation to other disease conditions (Bangdiwala et al., 1985; Garg and Hyder, 2006; Christie et al., 2007).

South Africa's population-based fatality rate is particularly high when compared with other LMICs, especially on the African continent. In an extensive review of 73 studies on RTIs in LMICs, Odero et al. (1997) considered 31 studies that included data on population and vehicle-based rates. Of the 13 studies reviewed in Africa, South Africa had the highest reported population-based fatality rate of 35.8 deaths per 100 000 population, followed by Swaziland with 28.0 deaths per 100 000 population. The lowest rate was reported for Tanzania with 4.0 deaths per 100 000 population. Generally, high population-based fatality rates were shown to be characteristic of countries having relatively higher income economies compared with other LMICs. However, South Africa was reported to have the lowest vehicle-based fatality rate of 20.5 deaths per 10 000 vehicles among these 31 studies. Based on data from the RTMC (NDoT, 2007), the level of vehicle ownership in South

Africa was 161 per 1000 people in 2006, a high value for the continent. The growing number of motor vehicles in LMICs is often blamed for their high burden of RTFs (Nantulya & Reich, 2002; Peden et al., 2004).

Geographical analyses provide a useful methodology for highlighting regional differences in the distribution of the risk of road traffic fatalities, and, as suggested by Whitelegg (1987), a geographical approach may also allow for an improved understanding of the nature, causes, and progression of these injuries. Systematic analyses of geographical distributions and variations in RTFs have not been undertaken in the South African context. Considering the escalating burden of road traffic deaths in South Africa, analyses of the geography of risk may provide new insights with which to guide intervention strategies targeted at reducing this public health challenge.

Characteristics such as those relating to rurality (or urbanisation) provide useful area-based dimensions for understanding the geography of road traffic deaths. Generally, unintentional injury death rates have been shown to be higher in rural than in urban areas (Peek-Asa et al., 2004; Boland et al., 2005). In terms of RTIs, higher death rates have also been reported for rural areas in Africa (Afukaar et al., 2003), Europe (Bentham, 1986; Boland et al., 2005) and the United States (Brown et al., 2000; Clark & Cushing, 2004; Peek-Asa et al., 2004; Zwerling et al., 2005; Paulozzi, 2006). In these studies, rurality is often defined using population density (Baker et al., 1987; Muelleman & Mueller, 1996; Clark & Cushing, 2004; Peek-Asa et al., 2004; Paulozzi, 2006). In terms of road users, studies in HICs have generally shown higher fatal injuries in rural areas for vehicle occupants (Baker et al., 1987; Chen et al., 1995; Muelleman & Mueller, 1996). However, pedestrian risk and injury are generally higher in urban areas. For example, Petch & Henson (2000) reported the risk of a pedestrian accident for children living in urban areas to be around five times higher than that for those living in rural areas. At present, it is not clear whether such rural-urban patterns in road traffic deaths manifest in LMICs such as South Africa.

Higher fatality rates in rural areas are often attributed to higher travel exposure, and poorer injury outcomes, owing to faster speeds and lower quality of medical care. However, the relationship between rurality and RTFs is complex, with some studies showing higher rural fatality rates to persist after controlling for these factors. For example, in the United States, Clark & Cushing (2004) showed population density to be a moderately strong predictor of rural but not urban traffic mortality rates, after controlling for vehicle miles travelled. In terms of injury severity, Muelleman et al. (2007) showed the risk of fatal RTIs to be nearly twice as high in rural areas of Nebraska (defined by population size and adjacency to a metropolitan area) even after controlling for injury severity.

While rural-urban variations in RTIs have not been studied in South Africa, previous small-area studies in rural settings suggest that disparities may be present. Kahn et al. (1999) showed a high prevalence of fatal injuries from all causes in Agincourt, a relatively small and rural sub-district with a population of about 63 000 people. Approximately one-third of all deaths among children aged 5-14 years, and also in the economically active group from 15-49 years were injury-related, whilst nationally, injuries account for only 12% of deaths from all causes (Bradshaw et al., 2003). In terms of road traffic fatalities, Meel (2007) showed a relatively high fatality rate of 63 per 100 000 population for Transkei, a largely rural region in the Eastern Cape of South Africa.

This paper addresses the paucity of South African data on epidemiological distributions in the risk of fatal RTIs. Demographic, road user and temporal characteristics are examined, and there is a particular focus on geographical variations in road traffic fatality risk. The efficacy of various measures of rurality for explaining the geographical variations in road fatality risks are examined, and the implications of the results for strategies to prevent or reduce the burden of road traffic deaths in South Africa are discussed.

2.2 Data and Methods

The study was based on a cross-sectional geographical design at the District Council Municipality (DC) census level. It focussed on all fatal traffic injuries occurring in South Africa from 2002 to 2006. Based on the new municipal structure implemented by the Municipal Demarcation Board in mid-2000 (StatsSA, 2004b), there are 53 DCs, including 6 Metropolitan areas and 47 District Councils that cover the remaining non-metropolitan areas. The DC level was the lowest level at which all data could be disaggregated for the analysis in this study. Furthermore, analysis at this scale, where significant resource, policy and intervention planning occurs, allows for a macro-level assessment to be undertaken of spatial variation among observed fatalities. The five-year study period included the earliest and most recent years for which comprehensive individual level traffic fatality data was available.

2.2.1 Outcome data and indicators

Table 2.1 provides a summary of the outcome measures, denominators, and measures of rurality examined. The data on road traffic deaths, supplied by the National Department of Transport (NDoT), is based on the routine completion of an 'accident report' form by police personnel for all traffic-related injuries (see Appendix 1).

Table 2.1: Summary of outcome and rurality measures for District Council Municipalities, 2002-2006

Variable	Source data	Min	DC Min	Max	DC Max	Mean
Outcome measures						
Total fatalities	NDoT	207	Namakwa	3 811	Johannesburg	947.3
Average annual fatalities per 100 000 population	NDoT, StatsSA	9.0	Alfred Nzo	114.1	Central Karoo	27.6
Average annual fatalities per 10 000 vehicles	NDoT, NHTS	7.3	Cape Town	105.0	Central Karoo	30.7
Denominators for outcome measures						
Total population	StatsSA	60 483	Central Karoo	3 225 812	Johannesburg	845 656.1
Total vehicle population	NHTS	6 571.9	Central Karoo	651 486.0	Cape Town	101 403.5
Rurality variables						
% Rural population	StatsSA	0.3	Johannesburg	99.0	Bohlabela	48.6
Population size (Total persons)	StatsSA	492.9	Chris Hani	1 055.7	Zululand	816.6
Crude population density (Persons per SqKm)	StatsSA	0.9	Namakwa	1 962.1	Johannesburg	180.4
Person-weighted population density (Persons per SqKm)	StatsSA	248.0	Umkhanyakude	15 319.9	Johannesburg	3 795.7

Key to data sources: NDoT- National Department of Transport (National Traffic Information System);
StatsSA- Statistics South Africa (Community Profiles Databases with 2001 population census and GIS data);
NHTS- South African National Household Travel Survey (2003 database, supplied by TRC Africa).

Fatalities occurring up to six days after a collision are deemed traffic-related and are included within a fatality database. There are some limitations with this definition as it is shorter than the 30 day cut-off recommended by the World Health Organisation for classifying victims of road traffic collisions (Peden et al., 2004). While less of a problem with fatal than non-fatal data, under-reporting of deaths in the police records used in our study is likely to have occurred. While the problem may be global (Peden et al., 2004), it is of particular concern in LMICs lacking resources (Odero et al., 1997). A French study (Aptel et al., 1999) that compared police, hospital and vital statistics showed that up to 15% of crash fatalities are not captured by police records. The study also showed higher levels of under-reporting in rural than in urban areas. In South Africa, the extent and nature of under-reporting is unknown, but is likely to be higher.

As the location of individual collisions is not recorded, the police station assigned to a traffic fatality provided the most reliable geographical reference for the events; hence boundary data for police stations was obtained from the 1997 Human Sciences Research Council Police Station Boundaries dataset. Boundary data for the DCs, based on the new municipal structure, was also extracted from the Statistics South Africa (StatsSA) Community Profiles Databases. Using the ArcGIS 9.2 Geographical Information System (GIS), the centroid (centre point) of each police station service boundary was determined and this location was used to allocate each road traffic fatality to its respective DC.

Data on demography, road user characteristics, and temporal and seasonal factors, were extracted from the Department of Transport fatality database. Two risk exposure measures, population counts and vehicle ownership, were included for the DCs. Travel-related exposure measures, such as driving distance or driving time were not included, because disaggregated data was not available at the DC level.

Population data for the DCs was based on the 2001 census population counts from StatsSA. Data on the registered vehicle population or vehicle ownership was not obtainable at the DC level; hence ‘vehicle access’ was used as a proxy measure. Data on household access to the number of vehicles in running order for private use within each DC was extracted from the South African National Household Travel Survey 2003 database. The measure included vehicles owned by households, vehicles owned by relatives/friends and vehicles owned by employers.

The fatality data and the risk exposure measures were used to produce two types of commonly used outcome indicators; the population and vehicle-based fatality rates. In calculating the indicators, the outcome data was averaged over the five-year study period and annualised rates were calculated. For the population-based fatality rate, the number of deaths (for population cohorts and DCs) was divided by the respective population exposed, and expressed as the number of deaths per 100 000 population. The overall age-adjusted directly standardised fatality rate was also calculated and compared with the overall crude rate for the DCs. The two rates showed to be very similar, and were highly correlated ($r=0.993$, $p<0.001$). Consequently, for consistency especially with the rurality quartile analyses where standardised rates were not appropriate, crude fatality rates were used throughout the study. In terms of the vehicle-based rates, the number of fatalities was divided by the total 'vehicle access' for each DC, and expressed as the number of deaths per 10 000 vehicles. Of note was that the national road traffic fatality rate of 18.7 per 10 000 vehicles calculated using data within this study, was similar to the rate of 16.8 per 10 000 registered vehicles reported by the RTMC for 2005 (NDoT, 2007).

2.2.2 Rurality data

Four variables relating to rurality were selected against which between-DC variations in mortality were examined. The rurality variables relate to physical area-based dimensions of rurality. Measures relating to social influences of deprivation were not included, because Index of Multiple Deprivation data was not available for the DCs, and it is well-recognised that deprivation indices generally measure urban disadvantage much better than rural (Niggebrugge et al., 2005).

The first variable calculated was the percentage of the population living in rural areas. Enumerator Areas are the lowest geographical level used for non-population based census dissemination, and are defined as rural or urban based on the predominant land use and type of settlement within the EA by StatsSA (StatsSA, 2003). For each DC, urban and rural populations for the Enumerator Areas were summed, and the percentage of the population living in rural areas was calculated.

The second measure was the average population size, calculated by averaging the populations of all census-defined Main Places within each DC. The Main Place level may be regarded as a comparable level with that used internationally for calculating population sizes and defining rurality (StatsSA, 2003). Main Places represent the third lowest census level (after EAs and Sub-places) and include cities, towns, tribal areas and administrative areas (StatsSA, 2004). Analysis using the StatsSA community profiles databases showed large variability in the population sizes of the 3 109 Main Places, with mean and median values of about 14 800 and 4 200 respectively.

The remaining two measures were crude population density and person-weighted population density. The crude measure was calculated for each DC by dividing the total population by the land area in square kilometres. To account for population clustering, the person-weighted population density was calculated for each DC, as the population-weighted sum of crude population densities for all ‘Small Areas’ within the DC. The Small Area Layer, created by combining all EAs with a population smaller than 500 with adjacent EAs within a Sub-place, is the lowest geographical level for which population data is available (StatsSA, 2005).

The four rurality variables were generally well correlated, with most correlation coefficients in excess of 0.7 and significant at the 1% level. Exceptions were the correlations between the percentage rural population and population density ($r=-0.43$, $p=0.001$) as well as between the percentage rural population and population size ($r=-0.41$, $p=0.003$).

2.2.3 Statistical analysis

The SPSS version 14.0 (SPSS Inc) software was used to explore associations between the outcome indicators and explanatory variables. For all statistical analyses, the level of significance was set at alpha=0.05. Confidence intervals around rates were calculated based on the formula [Rate ± (1.96*Rate/√N)], where N represented the number of cases over the 5-year study period.

2.3 Results

2.3.1 Demography and road user characteristics

The 53 DCs, aggregated from 1 030 police station areas, contained 50 205 recorded traffic fatalities over the five-year period 2002-2006. The pedestrian user group accounted for the highest proportion of traffic-related deaths (42.4%). Among pedestrians, and where demography was known, males accounted for 76.4%; blacks and coloureds combined made up 96.9%; and the 25-59 year age group made up 57.5% of cases.

Table 2.2 shows that pedestrian fatalities, at a rate of 9.5 per 100 000 population, were the largest proportional contributor to the national annual fatality rate of 22.4 deaths per 100 000 population. The fatality rate for passengers was higher than that for drivers (6.5 and 5.1 deaths per 100 000 population, respectively). In terms of ethnicity, Table 2.2 shows that there were very strong disparities between groups based on road user type. The highest traffic fatality rate per 100 000 population was among whites (28.7), due mainly to this group having the highest driver fatality rate of 15.7. The highest rates per 100 000 population for passengers was among Asians followed by coloureds (9.4 and 8.3, respectively) and for pedestrians was among coloureds followed by blacks (11.9 and 10.1, respectively).

The mortality rate amongst males of 34.9 was 3.5 times higher than the female rate of 10.1 per 100 000 population. Table 2.3 shows that the highest rates per 100 000 population (25.5) was among young adults (25-34 years) followed by 22.9 for older adults (35-59 years) with this pattern being consistent for both males and females. Only drivers (both male and female) and female pedestrians had higher rates among older compared with younger adults. The largest difference between male and female rates was among drivers, with values being 13 and 12 times higher for males in the 25-34 and 35-59 year age groups, respectively.

2.3.2 Temporal and seasonal variations

The findings of the temporal analyses, with fatalities assigned to the nearest hour of occurrence, showed that fatalities peaked over the evening hours (17h00-01h00 52.8%)

with 9.5% of cases occurring around 19h00 (Figure 2.1). Other peaks are apparent over weekends (Saturday & Sunday 42.4%), with 24% of cases occurring on Saturdays, and in December (12.7%). An examination of the distribution of deaths by road user type in Figure 2.1 shows that pedestrians accounted for by far the highest numbers of fatalities for all high-risk periods mentioned above, with the peak over evening hours being most notable. Analysis of the particularly high number of pedestrian fatalities during the evening hours revealed that cases were mostly male (77.8%), black (85.6%) and in the 35-59 followed by 25-34 year age groups (37.6% and 28.7%, respectively).

Table 2.2: Average annual fatality rates per 100 000 population, 2002-2006, for road user by ethnicity

	Vehicle Driver			**Vehicle Passenger**			**Pedestrian**			**Bicycle or Motorcycle Rider**			**Total**		
	N	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*
Asian/Indian	558	10.0	9.2-10.8	525	9.4	8.6-10.2	220	3.9	3.4-4.5	23	0.41	0.24-0.58	1 326	23.8	22.5-25.1
Black African	6 326	3.6	3.5-3.7	11 366	6.4	6.3-6.5	17 956	10.1	10.0-10.3	987	0.56	0.52-0.59	36 635	20.7	20.5-20.9
Coloured	1 057	5.3	5.0-5.6	1 649	8.3	7.9-8.7	2 367	11.9	11.4-12.3	221	1.1	1.0-1.3	5 294	26.5	25.8-27.2
White	3 369	15.7	15.2-16.2	1 641	7.6	7.3-8.0	439	2.0	1.9-2.2	720	3.4	3.1-3.6	6 169	28.7	28.0-29.5
Total[a]	11 438	5.1	5.0-5.2	15 495	6.9	6.8-7.0	21 286	9.5	9.4-9.6	1 984	0.9	0.8-0.9	50 205	22.4	22.2-22.6

[a]Totals for road users include cases with unknown ethnicity.

Table 2.3: Average annual fatality rates per 100 000 population, 2002-2006, for road user by age-sex group

		Vehicle Driver			Vehicle Passenger			Pedestrian			Bicycle or Motorcycle Rider			Total		
		N	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*	*N*	*Rate*	*95% CI*
Female	1-14	0	0	-	523	1.6	1.4-1.7	1 288	3.8	3.6-4.0	6	0.02	0.00-0.03	1 817	5.4	5.1-5.6
	15-24	99	0.42	0.34-0.50	800	3.4	3.2-3.6	541	2.3	2.1-2.5	21	0.09	0.05-0.13	1 461	6.2	5.9-6.5
	25-34	177	0.94	0.80-1.07	1 063	5.6	5.3-6.0	633	3.3	3.1-3.6	16	0.08	0.04-0.13	1 889	10.0	9.5-10.4
	35-59	298	1.1	0.93-1.17	1 374	4.9	4.6-5.1	1 049	3.7	3.5-3.9	21	0.07	0.04-0.11	2 742	9.7	9.3-10.1
	60+	67	0.66	0.50-0.82	323	3.2	2.8-3.5	312	3.1	2.7-3.4	1	0.01	0.00-0.03	703	6.9	6.4-7.5
Male	1-14	6	0.02	0.00-0.03	718	2.1	2.0-2.3	1 961	5.8	5.6-6.1	95	0.28	0.23-0.34	2 780	8.3	8.0-8.6
	15-24	806	3.5	3.3-3.8	1 324	5.8	5.5-6.1	1 567	6.9	6.5-7.2	285	1.3	1.1-1.4	3 982	17.5	17.0-18.0
	25-34	2 115	12.1	11.6-12.6	1 831	10.5	10.0-11.0	3 052	17.5	16.9-18.1	349	2.0	1.8-2.2	7 347	42.1	41.1-43.0
	35-59	3 249	13.1	12.6-13.5	1 887	7.6	7.3-7.9	3 783	15.2	14.8-15.7	462	1.9	1.7-2.0	9 381	37.8	37.0-38.6
	60+	374	6.0	5.4-6.6	229	3.6	3.2-4.1	620	9.9	9.1-10.7	60	0.96	0.71-1.20	1 283	20.4	19.3-21.6
Total[a]	1-14	6	0.01	0.00-0.02	1 261	1.9	1.8-2.0	3 255	4.8	4.7-5.0	101	0.15	0.12-0.18	4 623	6.9	6.7-7.1
	15-24	906	2.0	1.8-2.1	2 135	4.6	4.4-4.8	2 109	4.5	4.4-4.7	306	0.66	0.59-0.73	5 456	11.8	11.5-12.1
	25-34	2 294	6.3	6.0-6.6	2 907	8.0	7.7-8.3	3 694	10.2	9.8-10.5	365	1.0	0.9-1.1	9 260	25.5	24.9-26.0
	35-59	3 553	6.7	6.5-6.9	3 275	6.2	6.0-6.4	4 838	9.1	8.9-9.4	484	0.91	0.83-0.99	12 150	22.9	22.5-23.3
	60+	442	2.7	2.4-2.9	552	3.4	3.1-3.6	933	5.7	5.3-6.1	61	0.37	0.28-0.47	1 988	12.1	11.6-12.7

[a]Totals for age groups include cases with unknown sex.

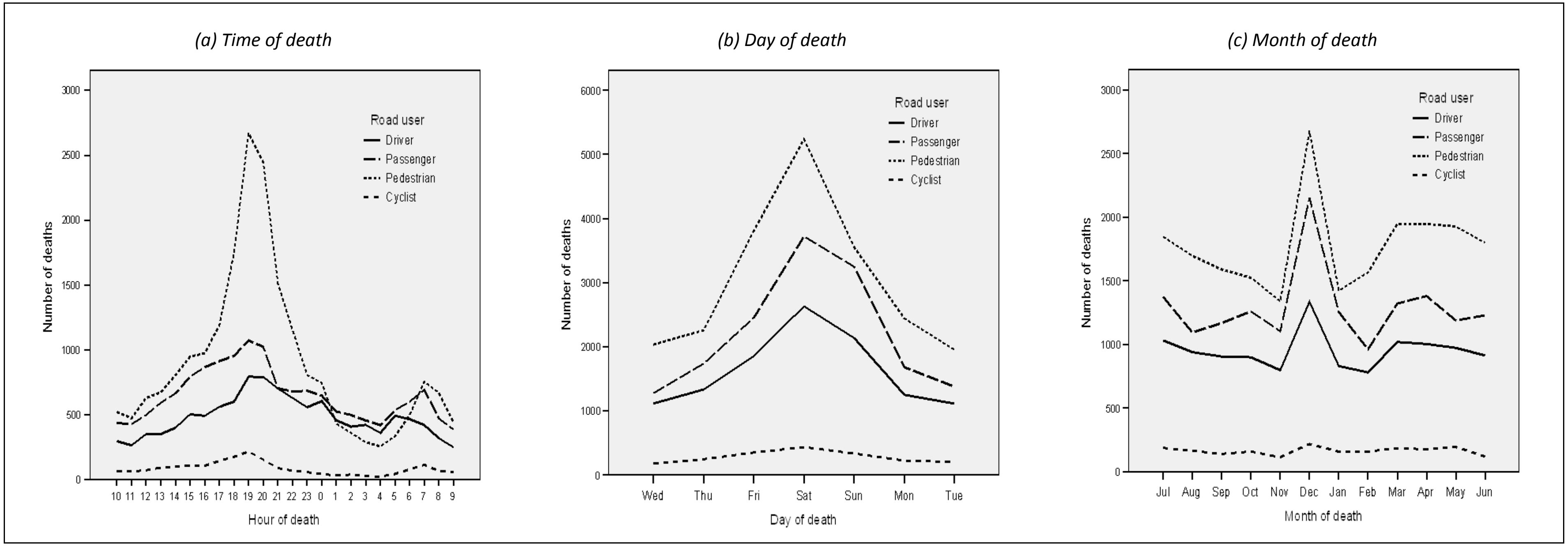

Figure 2.1: Road user by temporal and seasonal variations in fatalities, 2002-2006 (n=50 203)

2.3.3 Variations associated with rurality

Figures 2.2-2.3 show the average annual fatality rates (with 95% confidence intervals) for the two outcome indicators by quartiles of the four rurality variables. Quartiles are ordered by increasing rurality for each of the rurality variables.

With the overall population-based fatality rate, and in terms of the percentage rural population and person-weighted population density measures, Figure 2.2.a shows that the highest fatality rates are in relatively urban areas (quartile 2). In terms of the remaining rurality variables (population size and crude population density), the highest fatality rates are apparent in the most rural areas (quartile 4). With the pedestrian group, population-based fatality rates are similar across the rural and urban quartiles, but a slight decreasing trend with increasing rurality is apparent (Figure 2.2.b). In terms of the non-pedestrian group, the pattern in fatality rates across the quartiles is similar to that found for the overall combined group (Figures 2.2.c & 2.2.a).

In terms of the overall vehicle-based fatality rate (Figure 2.3.a), the lowest rates for all rurality variables are clearly apparent in the most urban areas (quartile 1). Both the pedestrian and non-pedestrian groups show a similar pattern to the overall group in the variation of vehicle-based fatality rates across the different rurality quartiles. However, there is a greater differentiation between highly urban areas (quartile 1) and other areas for the non-pedestrian group than the pedestrian group (Figures 2.3.c & 2.3.a).

2.3.4 Geographical variation

Figures 2.4-2.7 show maps of the geographical distribution of fatalities by the outcome indicators. Figure 2.4 shows that the highest population-based fatality rates are concentrated in the South West and North East of the country. The character of the DCs with the highest fatality rates conforms to the earlier finding of an elevated risk in areas with an urban character when rurality was defined by percentage rural population and person-weighted population density. This is particularly the case for the concentration of DCs in the South West of the country, where five of the six DCs (including Central Karoo) are in quartile 2 of both the rurality measures (Namakwa was the exception, being in quartile 3 of person-weighted population density).

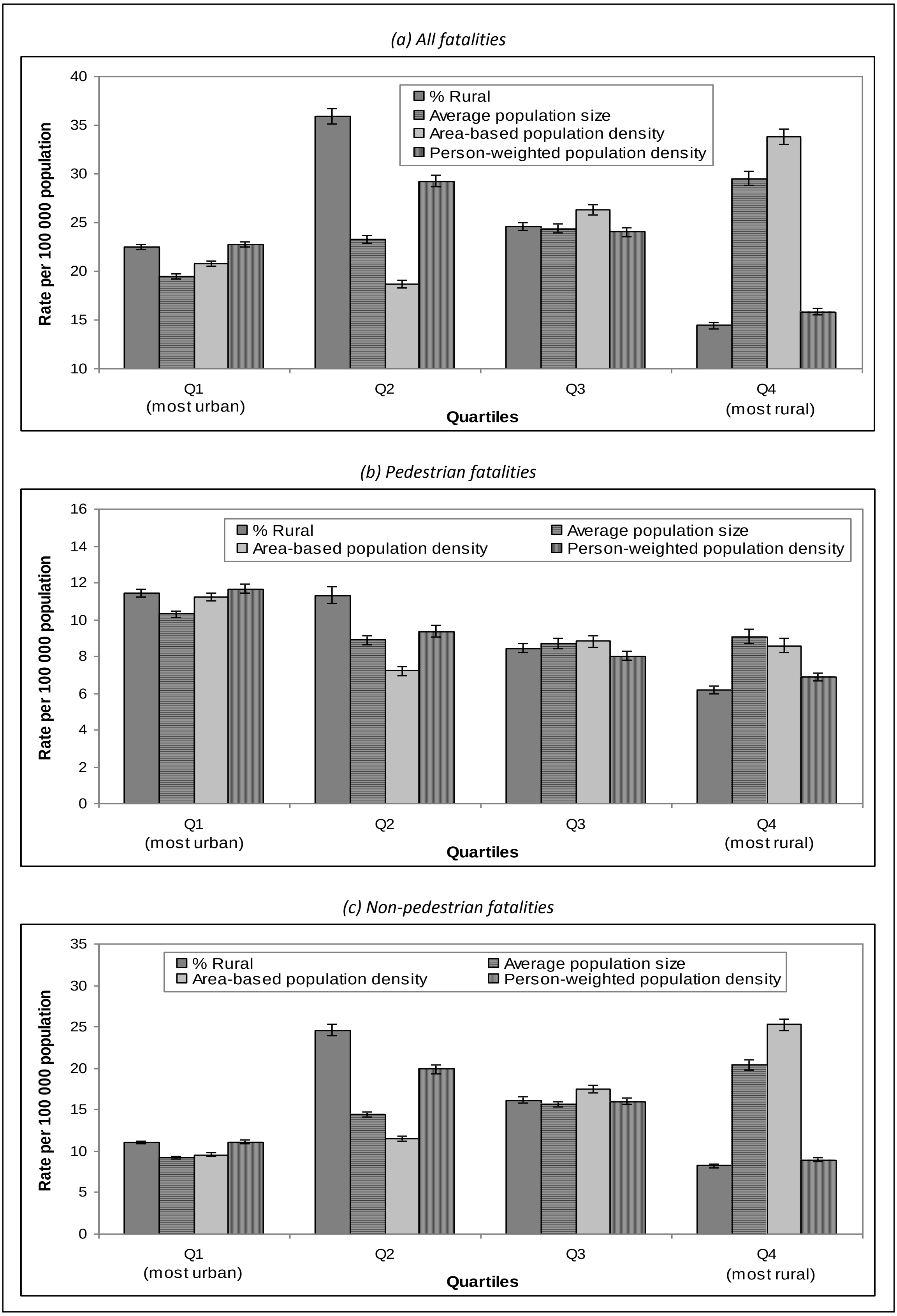

Figure 2.2: Average annual fatality rates per 100 000 population by quartiles of rurality variables and road user group, 2002-2006

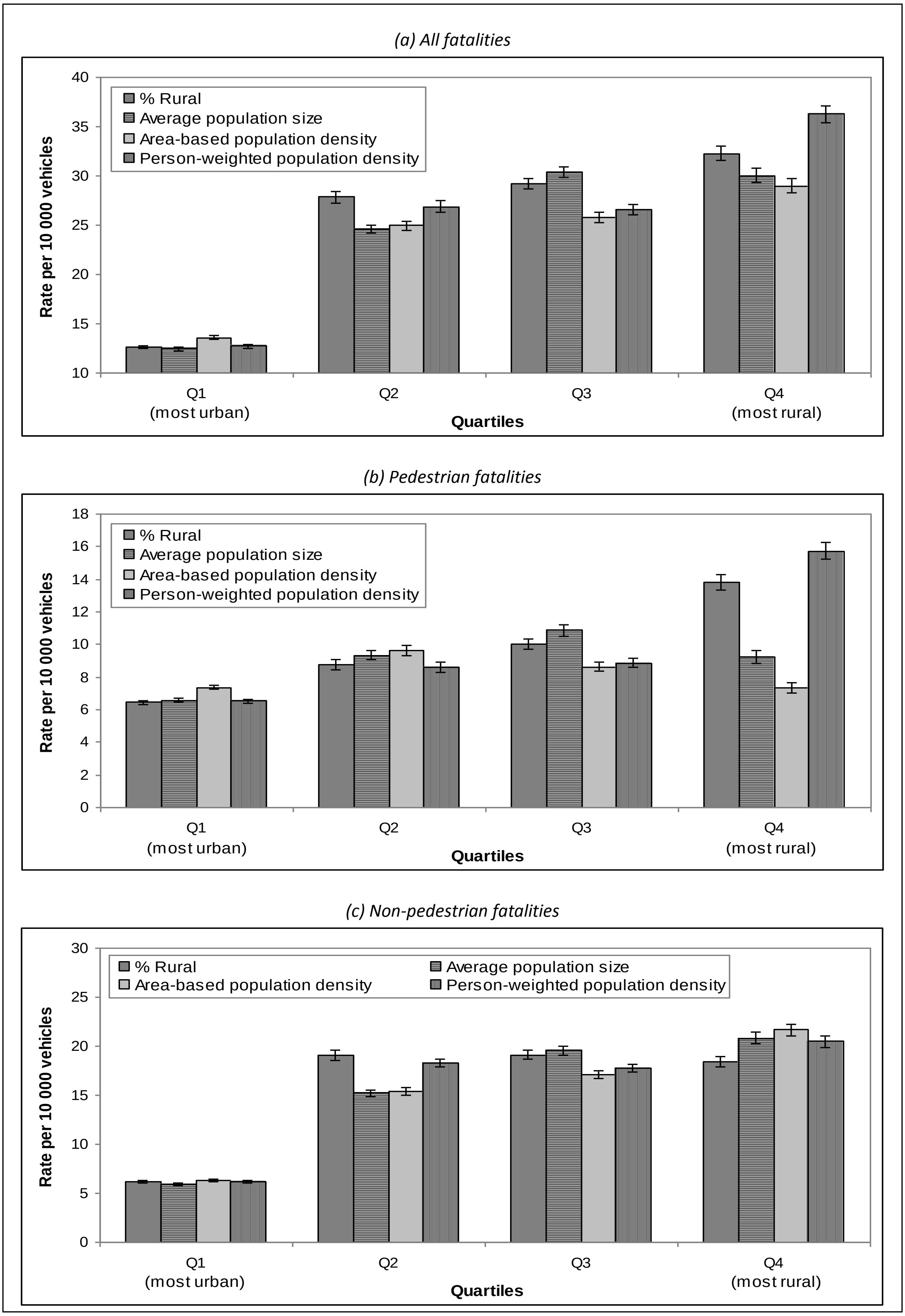

Figure 2.3: Average annual fatality rates per 10 000 vehicles by quartiles of rurality variables and road user group, 2002-2006

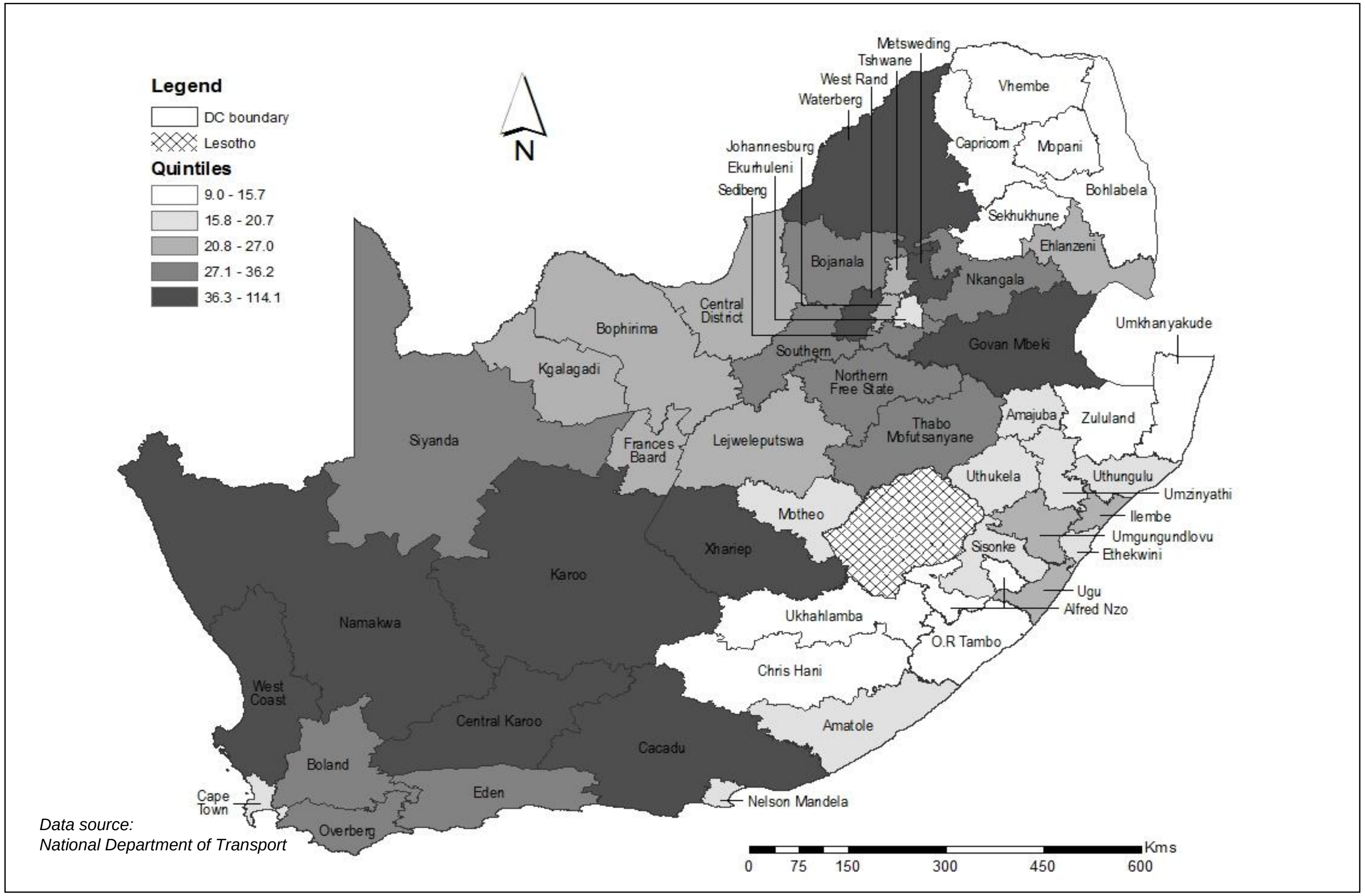

Figure 2.4: Fatality rate per 100 000 population for District Council Municipalities in South Africa (2002-2006 annual average)

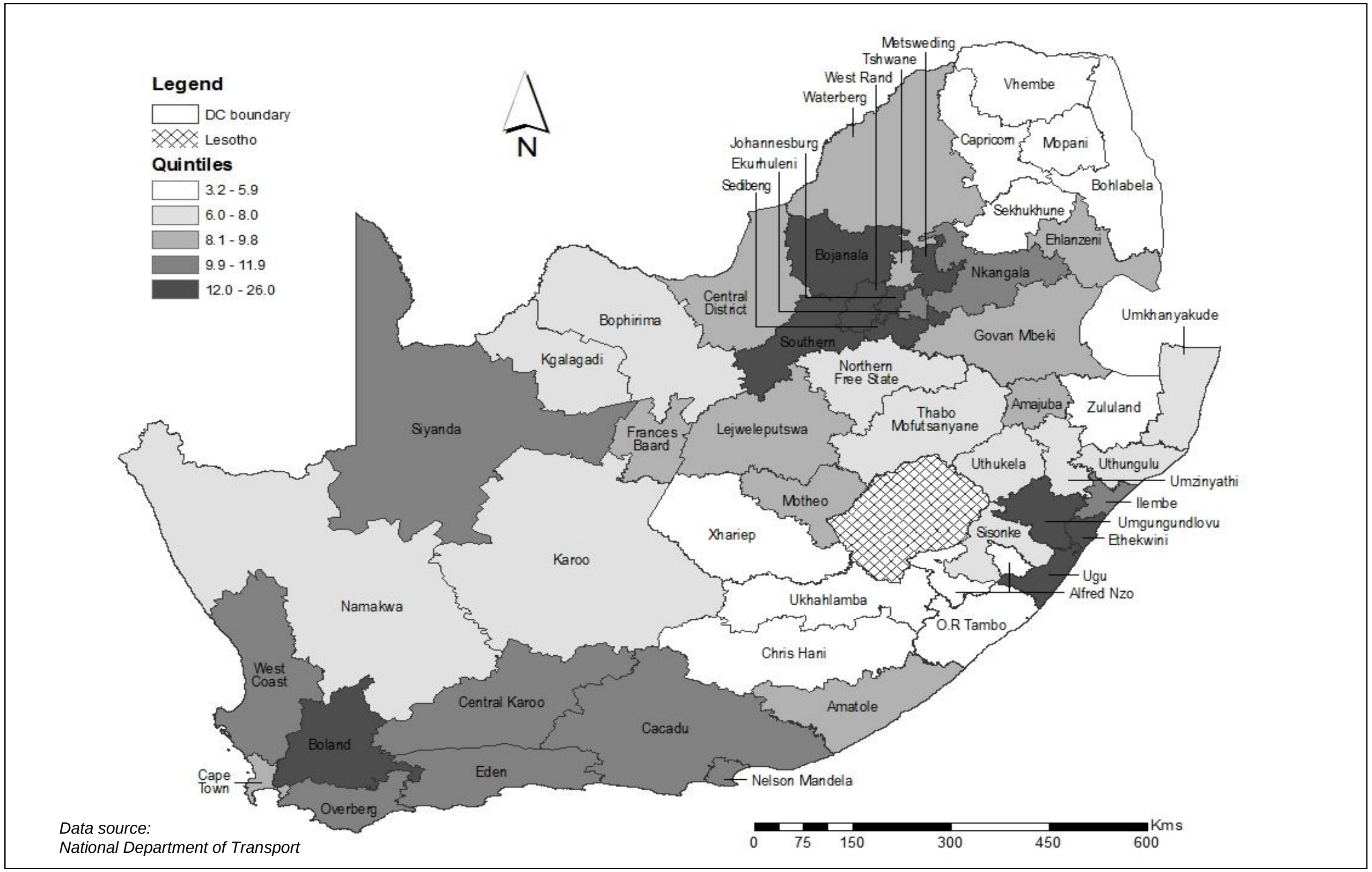

Figure 2.5: Pedestrian fatality rate per 100 000 population for District Council Municipalities in South Africa (2002-2006 annual average)

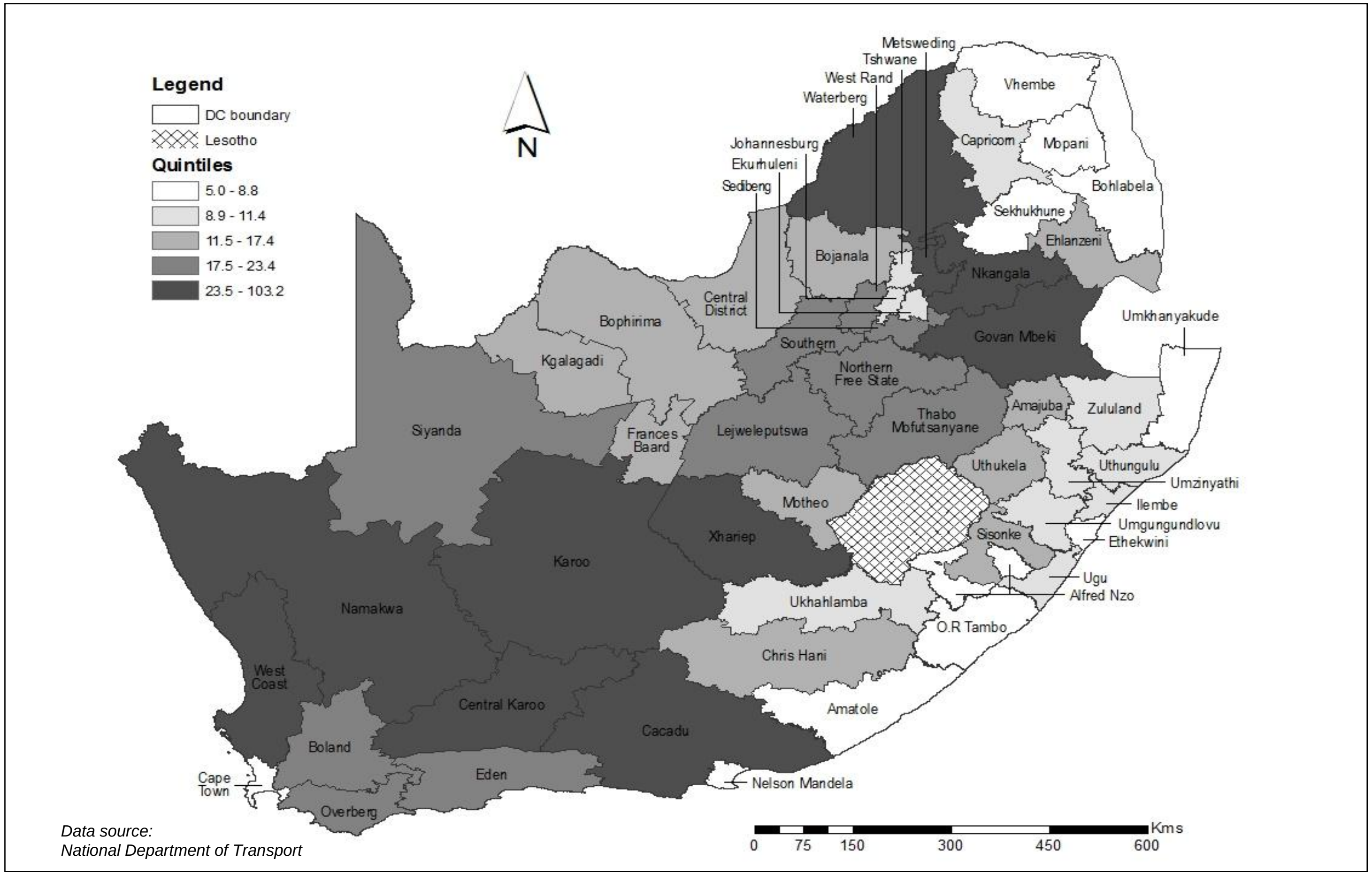

Figure 2.6: Non-pedestrian fatality rate per 100 000 population for District Council Municipalities in South Africa (2002-2006 annual average)

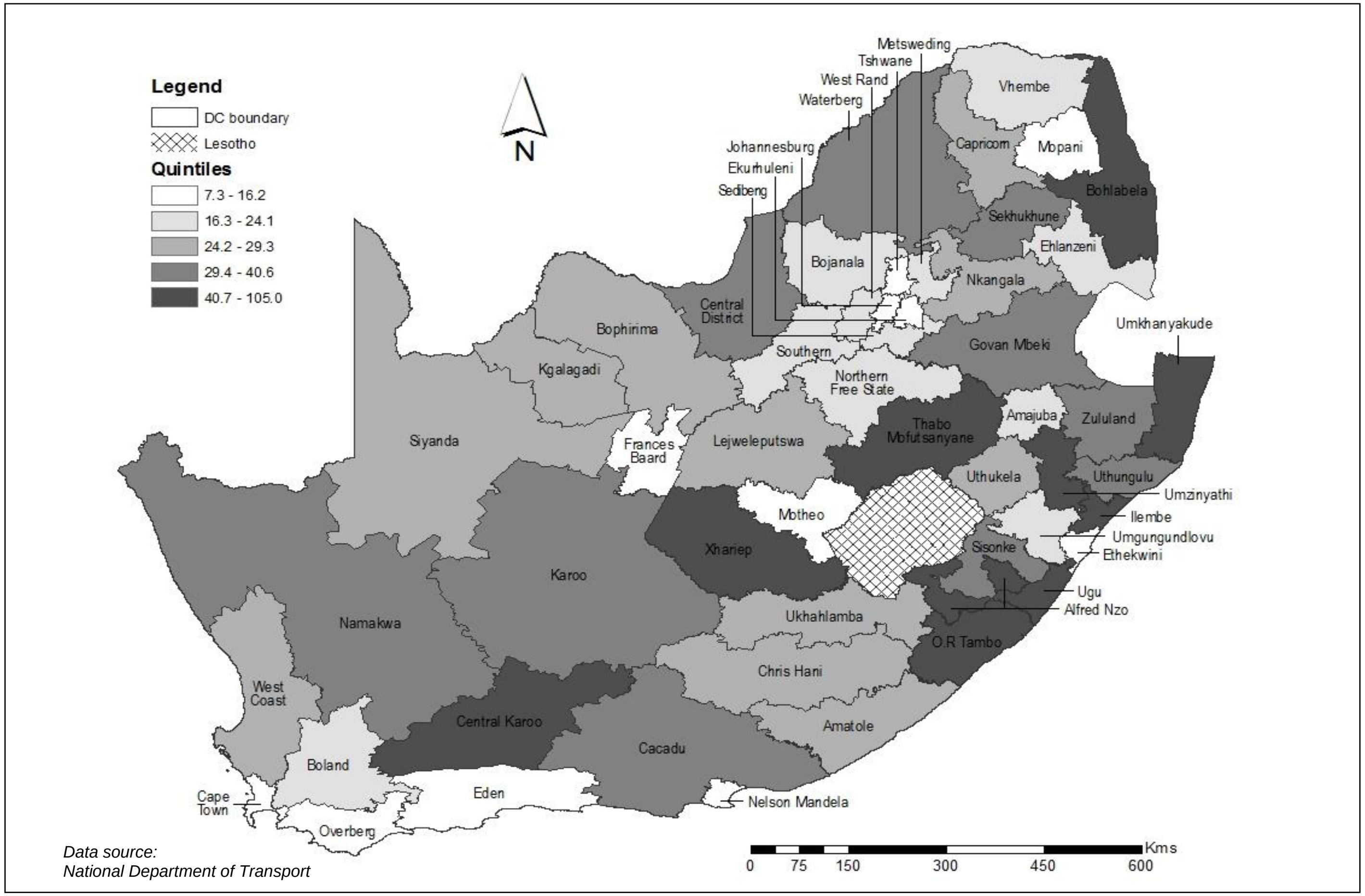

Figure 2.7: Fatality rate per 10 000 vehicles for District Council Municipalities in South Africa (2002-2006 annual average)

The difference in distribution of the population-based fatality rates for pedestrian and non-pedestrian fatalities is shown in Figures 2.5 and 2.6. With the exception of one DC in the South West (Boland), the remaining quintile of DCs with the highest pedestrian fatality rates are concentrated in the North/North East (North West and Gauteng Provinces) and in the Eastern Province of KwaZulu-Natal (Figure 2.5). The non-pedestrian fatality rate shows a similar distribution to the overall population-based fatality rate (Figure 2.6). Among the pedestrian group, most of the DCs with the highest fatality rate have urban characteristics on most of the rurality variables, and include the two largest metropolitan areas, Johannesburg and eThekwini (Durban). Metsweding, showing urban characteristics only on the percentage rural population measure and Ugu, only on the measure of crude population density, are exceptions. Among the non-pedestrian group, most of the DCs with the highest fatality rate also have an urban character but only on the percentage rural and person-weighted population density measures (quartile 2), also similar to that found for the overall population-based fatality rate. It is of note that only Metsweding, with the highest pedestrian fatality rate, is present among the DCs with a high fatality rate for both the pedestrian and non-pedestrian groups.

Finally, in terms of the vehicle-based fatality rate, Figure 2.7 shows Central Karoo to be among the quintile of DCs with the highest fatality rates, with the remaining DCs generally located in the Eastern part of the country. Most of the DCs with the highest vehicle-based fatality rates are rural, based on the percentage rural population and person-weighted population density. Central Karoo and Xhariep are exceptions, considered urban (quartile 2) on both these measures.

2.4 Discussion

Our study shows the occurrence of RTFs in South Africa to be complex, with substantial variation in population, temporal and seasonal characteristics, and in the geographical distribution of cases. Furthermore, geographical analyses showed large rural-urban disparities between DCs that differed by the category of road user and according to the measures used to quantify risk and to define rurality.

The large burden of road traffic fatalities, especially in LMICs, among historically disadvantaged populations, males, the economically active age groups, and the pedestrian road user group is well documented in the literature (see Odero et al., 1997; Peden et al., 2004). The relatively high driver rates among whites and males found in this study may be related to relatively higher vehicle ownership or relatively more frequent travel as vehicle drivers among these groups. However, these measures of exposure could not be assessed in this study, because disaggregated data were not available.

Our finding of relatively higher fatalities over evening hours and weekends is consistent with other studies in LMICs (Odero et al., 1997). The elevated risks suggested by our findings may relate to higher alcohol-related deaths over these peak periods, as shown in a study of all alcohol and injury-related fatalities occurring in the city of Durban from 2001-2004 (Sukhai, 2005). The finding in this study of a large peak in fatalities over December appears to be anomalous, given the observation by Sukhai (2005) of a relatively low percentage of alcohol-related deaths for this month (6%). However, greater mobility and exposure, in terms of higher leisure-related and migrant worker travel over this, and to a lesser extent, the Easter festive periods, may be an important contributing factor. For example, findings from the RTMC (NDoT, 2007) showed the month of December (together with March and November) to have the highest percentages of fuel sales, which is suggestive of relatively higher traffic volumes and hence travel exposure during these months.

In terms of rurality, our study shows that the trend in traffic fatality risk across the urban-rural continuum to be non-linear, but other clear associations are apparent. The vehicle-based fatality rate showed to be a better discriminator than the population-based fatality rate at differentiating rural-urban fatalities, and showed highly urban areas in quartile 1 to have the lowest fatality rates.

The population-based rate showed a less clear differential across the different indicators of rurality, although higher mortality was apparent for urban areas when rurality was measured according to the percentage rural population and person-weighted population density measures. It is notable that the finding of higher road traffic fatality rates in urban areas was only apparent for urban areas located in quartile 2 of these measures. These DCs may be categorised as non-metropolitan urban areas that are sparse, but with large clustered populations; suggesting that increased travel exposure may play a role in the heightened fatality risk in these areas. However, Central Karoo may have contributed to the high fatality rates in these urban areas. Central Karoo was ranked among the lowest ten DCs in terms of the number of fatalities but, with its exceptionally low population, it had a very high fatality rate of 114 per 100 000 population and could have inflated the rates for the quartiles in which it was located. Central Karoo was located in quartile 2 with percentage rural population and person-weighted population density measures (and quartile 4 with population size and population density), which were the same rurality quartiles that showed peaks in the population-based fatality rate.

Examination of Central Karoo highlights some of the difficulties in measuring rurality in this context, and may also explain the weak correlations found between some of the rurality variables shown earlier. Figure 2.8 shows the population distribution by census Small Area for Central Karoo. The population is generally concentrated in a few Small Areas, mostly owing to the area's large semi-desert and uninhabitable nature. With having more sparsely than densely populated Small Areas (and Main Places), the average population size is very low and hence, Central Karoo is considered highly rural (quartile 4) on this measure. A further difficulty is associated with differences in the physical size of the geographical areas being compared, which is especially important when delineating rural and urban areas. For example, in using the population size measure, Main Places in rural areas were on average twice as big in terms of land area (636 versus 321 square kilometres), but the average population size was one-quarter times smaller (7 557 versus 29 067 people) when compared with urban areas. Compared with other DCs, Central Karoo has the lowest population of about 60 500; approximately half that of the DC with the second-lowest population (Namakwa). With a very small population and a very large land area, Central Karoo has an extremely low crude population density, and is also considered highly rural (quartile 4) on this measure. Hence, the measure does not take account of the large areas of uninhabitable land that is included in the denominator of the measure but is not relevant to the population in the numerator. The use of this measure is therefore restricted, especially when the geographical areas being compared are characterised by large differences in population distributions. The very small population in Central Karoo is primarily (approximately 80%) urban, based on the census categorisation of rurality. Furthermore, when weighted by the large populations in the large census Small Areas, Central Karoo has a relatively high person-weighted population density (it is located in quartile 2) and hence is more appropriately considered urban, as compared with rural, using the un-weighted population density measure.

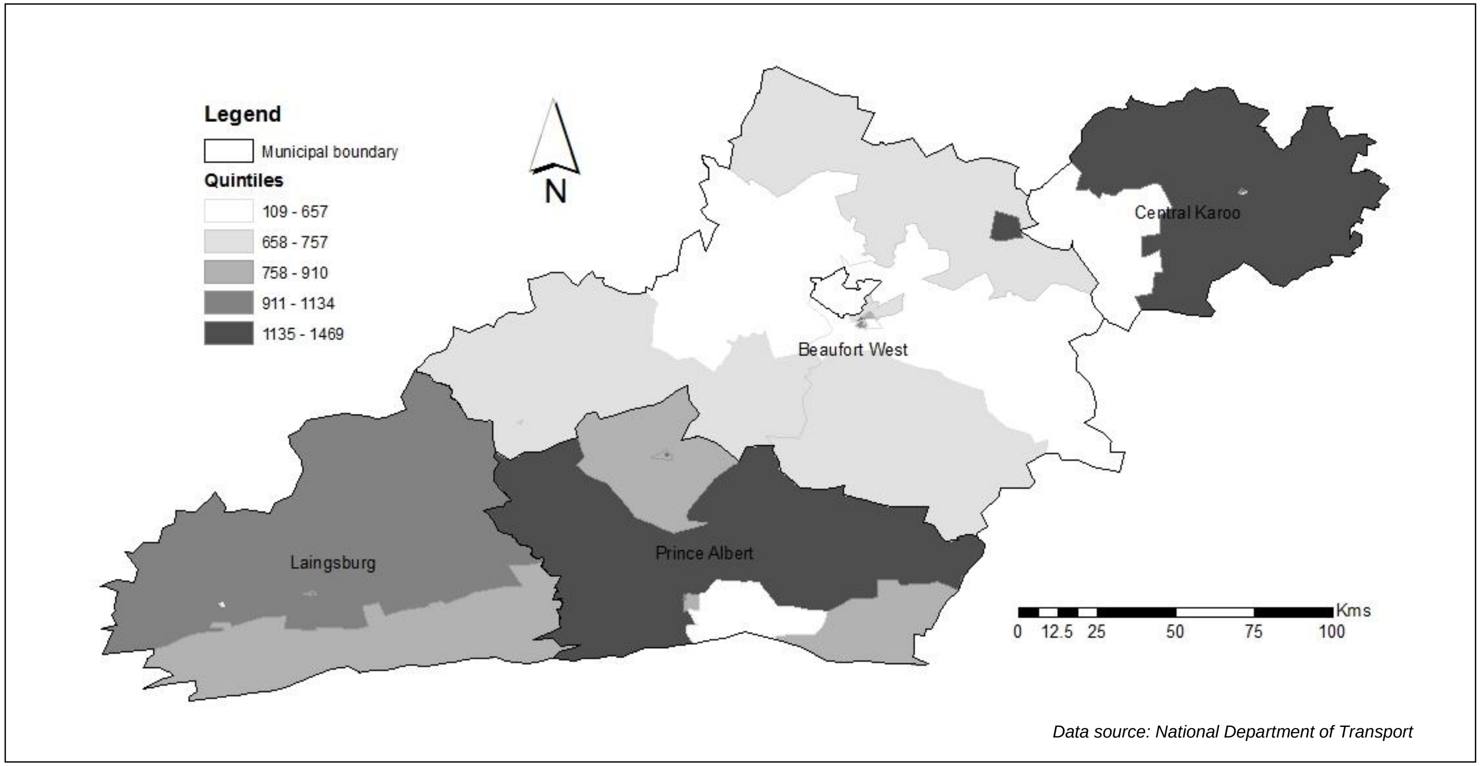

Figure 2.8: Population distribution for Central Karoo District Council by census Small Area

As a result of the significant weaknesses with the population size and crude population density measures, the percentage rural population and the person-weighted population density measures may be more reliable measures of rurality, at least in the South African setting. The percentage rural population measure has the advantage of capturing rurality at a very fine spatial resolution, while the person-weighted population density takes cognisance of the arrangement of the settlement types and landscapes, which is an important consideration, owing to the large diversity of geographical areas in South Africa.

Although the population-based fatality rate did not show clear trends according to rurality, it was the only measure to show a distinctive difference between the pedestrian and non-pedestrian groups in the patterning of fatality rates across the rurality quartiles. The pedestrian group showed a slightly decreasing trend with increasing rurality, in terms of the population-based fatality rate. Vehicle-based fatality rates were also shown to be higher for pedestrians in highly urban areas (quartile 1) than for non-pedestrians in highly urban areas. The relatively stronger link between pedestrian fatalities and urbanisation in our study is consistent with the heightened risk for pedestrians in urban environments reported by Petch and Henson (2000), amongst others.

The choice of denominators and difference in their magnitude between rural and urban areas has been shown to introduce a large amount of rural-urban variation in fatality rates in this study. Intuitively, we would anticipate the choice of denominator used to influence patterns of fatalities because, holding all other factors constant, areas with higher populations and more vehicles are expected to have more crashes and fatalities. However, areas with relatively high rates may be the result of an exceptionally low exposure in the denominator or an exceptionally high incidence of cases in the numerator of the rate. Rural areas are generally sparsely populated in terms of people and vehicles and would be expected to have higher population and vehicle-based fatality rates, although exceptions to this general trend were shown in our study. Higher vehicle-based fatality rates may also be due to the numerator representing an excessively high incidence of fatalities as a result of longer or more frequent journeys in rural areas.

Intuitively, road length may also be considered a potential denominator for comparing traffic fatality risk between areas. However, unlike the population and vehicle denominators, areas with higher road lengths may not necessarily be associated with more crashes and fatalities. For example, areas with relatively high road lengths may have a higher fatality risk owing to higher exposure from travel distances, but this may be offset by a lower risk if the probability of vehicle and person interactions is reduced in the more dispersed network. Hence, the relationship between road length and traffic fatality risk is unclear, and the usefulness of the indicator may be questionable, especially in the absence of related travel exposure data.

2.5 Conclusion

This study makes an initial contribution to the study of risk and geographical variations of road traffic deaths in South Africa. Important population-related risks have been demonstrated, and it is also clear that rurality is an important contextual consideration in the occurrence of road traffic deaths in South Africa. Studies that have examined rural-urban variations in road traffic deaths have often measured rurality based solely on population density and traffic fatality risk according to population exposure. Furthermore, fatalities are rarely disaggregated by road user groups. Our findings would suggest that these approaches are restricted in showing just one dimension of several, and caution is necessary in order that biased conclusions are not drawn.

Further research should be undertaken to better understand the disparities shown in this study. In terms of risk, measures of traffic-related exposure should be expanded upon, and disaggregated risk estimates such as for different temporal and seasonal groupings as well as for the different population and road user cohorts calculated. Further dimensions of rurality should also be examined, but with a more extensive range of environmental and demographic indicators included to more fully explain the broader geographical variations of road traffic deaths in South Africa. Additionally, South Africa's legacy of apartheid that dictated place of residence and controlled the movement of people, may also have a significant impact on the distribution and magnitude of road traffic deaths in the country, and these largely unmeasured socio-ecological effects should be investigated.

There is no single simple definition of risk or rurality because it depends largely on how the two indicators are measured, as well as on the nature of data aggregation. However, the census-defined percentage rural population and the person-weighted density measures were shown to be generally better measures for defining rurality in the South African context. Hence, caution is particularly important when risk and rural-urban criteria are used to guide policy and to allocate resources for road safety initiatives.

Chapter 3

Temporal variations in road traffic fatalities in South Africa

ABSTRACT

The annual road traffic fatality (RTF) burden of 43 deaths per 100 000 inhabitants in S.A is disproportionately high in comparison to the world average of 22 per 100 000 population. Recent research revealed strong geographical variations across district councils in the country, as well as a substantial peak in mortality occurring during December. In this study, the factors that explain temporal variations in RTFs in S.A are examined. Using weekly data from the period 2002-2006 for the country's nine provinces, non-linear autoregression exogenous (NARX) regression models were fitted to explain variations in RTFs and to assess the degree to which the variations between the provinces were associated with the temporal variations in risk factors. Results suggest that a proportion of the variations in weekly RTFs could be explained by factors other than the size of the province population, with both temporal and between-province residual variance remaining after accounting for the modelled risks. Statistically significant associations were found with travel exposure, levels of alcohol consumption, and school holidays; with the measures showing a positive association with the occurrence of RTFs. Policies directed at reducing the effects of the modifiable risks identified in our study will be important in reducing RTFs in S.A.

3.1 Introduction

The annual road traffic fatality (RTF) burden of 43 deaths per 100 000 population in S.A is disproportionately high in comparison to the world average of 22 per 100 000 population (Bradshaw et al., 2001; Murray et al., 2001). A general increasing trend in fatalities has also been reported, with deaths in 2006 being 42% higher than those recorded in 2001 (NDoT, 2007). The large and growing burden of RTFs in LMICs such as S.A is a particular public health priority; while RTFs are forecast to decrease by about 30% in HICs over the next 15-20 years; RTFs in LMICs are expected to increase on average by around 80% if current policies and practices continue without novel interventions (Peden et al., 2004).

Recent research examining the epidemiology of RTFs in S.A using several exposure-based indicators of risk showed strong geographical variations across district councils (Sukhai et al., 2009). Additionally, marked variation was shown throughout the year, with a substantial peak in mortality occurring during December. The reasons for this have not been quantified. Nevertheless, the excess of RTFs in December is similar to that shown in recent years for data in Australia (Department of Infrastructure, Transport, Regional Development and Local Government, 2008) whilst fatal crashes in the USA have generally peaked in July (NHTSA, 2008).

Research attempting to explain temporal variations in RTFs is commonly undertaken to understand the long-term effects of interventions such as random breath testing for alcohol (Dunbar et al., 1987), seat belt usage (Houston & Richardson, 2002; Majumdar et al., 2004), and speed limitation (Johansson, 1996), or changes in traffic-related risks such as the role of alcohol or travel-related exposure (Fridstrøm et al., 1995; Ramstedt, 2008). Where temporal variations in RTFs within a year have been studied, the focus has generally been on seasonal influences. Much of this work has been undertaken in the northern hemisphere, especially Scandinavian countries (Johansson, 1996; Radun & Radun, 2006) and findings generally point to an excess of traffic fatalities in summer. The summer excess may be associated with higher traffic volumes, or the effect of risk compensation where drivers reduce their speed in poorer winter driving conditions to offset the weather-related hazards (Fridstrøm et al., 1995). Driver fatigue as a result of the heat has also been suggested as a possible contributor to excess summer deaths (Johansson, 1996; Radun & Radun, 2006).

The suggestion of seasonal effects in many previous studies is often based on proxies of unmeasured risks and the findings are of limited use in the design of interventions. Furthermore, little is known as to whether the risks identified in HICs are the same as those in low- to middle-income countries such as S.A. In this research, undertaken to provide new evidence on these issues, weekly data covering the 9 provinces of S.A for the period 2002-2006 are used to fit non-linear autoregression models. The models identify the predictors of temporal variations in RTFs in the country, and examine the degree to which spatial disparities in these temporal risks may explain the previously reported between-area variations in RTFs.

Table 3.1: Summary of variables generated for the study

Variable	Geographic level & source	Temporal resolution	Min	Max	Mean	SE
Outcome						
Number of fatalities by province and week	Province[a]	Weekly	0	93	21.38	0.29
Traffic-related measures						
Volume of fuel (petrol and diesel) sold for road use (megalitres, 10^6 L)	Province[a]	Monthly	27.63	506.29	148.64	2.42
Number of registered motorised vehicles (x 10^{-6})	"	"	0.13	2.94	0.74	0.01
Population size of province (x 10^{-6})	Province[b]	Yearly	0.82	9.92	5.12	0.06
Average blood alcohol concentration (mg/100ml)	National[c]	Weekly	48.75	303.33	104.18	0.48
Rate of driver licensing (per 100 000 population >14 years)	"	Cross-sectional	1.16	3.94	2.19	0.02
Length of road network (10^3 kms)	"	"	55.00	111.35	82.35	0.43
Weather and daylight						
Total average daily rainfall (mms)	Province[d]	Weekly	0	95.21	10.53	0.28
Average daily maximum temperature (°C)	"	"	13.77	35.82	25.39	0.09
Average daily visibility (kms)	"	"	15.62	43.29	30.15	0.12
Average daily sunshine (hrs)	"	"	1.70	13.13	8.20	0.04
Average daily wind speed (metres/sec)	"	"	6.22	17.17	10.54	0.04
Average number of frost days	"	"	0	5.33	0.29	0.01
Average number of hail days	"	"	0	0.38	0.02	0.0009
Average number of fog days	"	"	0	3.43	0.26	0.01
Average number of snow days	"	"	0	0.88	0.01	0.0008
Total daylight (hrs)	Province[e]	"	69.18	100.98	84.69	0.18
Days of public holidays						
Number of public holidays occurring over weekdays	National[f]	Weekly	0	2	0.20	0.01
Number of long weekends (national public holidays adjacent to a weekend)	"	"	0	2	0.12	0.01
Number of school holidays (including national public holidays) occurring over weekdays	Province[f]	"	0	5	1.25	0.04

[a] Department of Transport - National Traffic Information System; [b] Statistics South Africa (StatsSA) mid-year population estimates; [c] MRC-UNISA Crime, Violence & Injury Lead Programme - National Injury Mortality Surveillance System (NIMSS); [d] South African Weather Service; [e] U.S. Naval Observatory; [f] SA Embassy and Government Information

3.2 Methodology

The dataset assembled for the analysis consisted of 260 weeks, beginning Sunday 6th January 2002 and ending Saturday 30th December 2006. For each week, a separate record was produced for each of the 9 provinces in S.A, resulting in 2340 observations in total. The data sources used to generate this dataset are discussed below.

3.2.1 Road traffic fatalities

Table 3.1 details the 20 variables computed for this research. The data on weekly RTFs in each of the 9 provinces of S.A was supplied by the National Department of Transport (NDoT). It was based on the routine completion of an 'accident report' form by police personnel for all traffic-related injuries (see Appendix 1). Fatalities occurring up to six days after a collision were deemed traffic-related, and the dates and times recorded related to the occurrence of the crash rather than the death. From this, the outcome variable for modelling was computed as the total fatalities for each week in each province for the period 2002-2006.

3.2.2 Traffic-related explanatory variables

The explanatory variables examined are listed in Table 3.1 according to risk category. Traffic-related exposure is a major contributor to traffic crashes. Fridstrøm et al. (1995) measured the relative contribution of randomness, exposure, weather, and daylight to variations in accident counts among four Nordic countries, and found traffic-related exposure to be the most important factor, accounting for 70% of the systematic variation in injury accidents and 50% of fatal accident variations. Whilst traffic volume is considered a relatively direct measure of travel-related exposure (Fridstrøm et al., 1995), information on temporal variations in vehicle volumes is not available in S.A, therefore three temporal and two cross-sectional proxies were generated (see Table 3.1). Data on monthly fuel sales was available for each province, and the monthly values were assigned to each week falling within the corresponding month. Monthly data on registered motorised vehicles was assigned in the same way. Information on the number of licensed drivers was only available for the period 2004-2006, and data was used to produce a single cross-sectional measure of the average annual number during that time period for each province. In order to standardise this measure according to the size of the resident population aged over 14 years, mid-year population estimates from the S.A Census for the year 2005 were used as the denominator of a rate. The length of all roads used for vehicle travel was assigned to each province as a cross-sectional measure, which did not vary over time. Yearly population sizes were generated based on mid-year estimates for each province, and all weeks falling within a given year were assigned the corresponding annual value for the province.

An additional traffic-related risk factor is associated with the alcohol consumption of road users. This may represent a particularly substantial burden in countries such as S.A. For example, in a review of studies conducted in LICs, alcohol was shown to be present in the blood of between 33% and 69% of all fatally-injured drivers (Odero & Zwi, 1995). For this research, estimated temporal variations in alcohol consumption amongst the road user population were proxied based on blood alcohol concentrations of traffic fatalities. This data was available from the Medical Research Council & University of South Africa's National Injury Mortality Surveillance System (NIMSS). In 2005, the NIMSS, which contains information of a sub-sample of deaths, accounting for 39% of all non-natural mortality in South Africa of which 40%, were traffic-related. Data on blood alcohol concentrations amongst all cases tested were supplied for the period 2002-2005, and weekly estimates were computed for 2006 based on the mean values for the preceding four years. Owing to the limited geographical coverage of the NIMSS data, national values were assigned to each province.

3.2.3 Weather-related explanatory variables

Previous studies have shown several weather conditions to be associated with crash or fatality risk. Rainfall has been associated with an increased crash risk (Fridstrøm et al., 1995; Eisenberg, 2004; Eisenberg & Warner, 2005) while snow has been associated with a reduced risk of fatal crashes (Scott, 1986; Brodsky & Hakkert, 1988). Precipitation is thought generally to reduce the severity of those collisions that do occur owing to risk compensatory behaviour, resulting in slower travelling speeds (Fridstrøm et al., 1995). The literature on the relationship between temperature and fatalities is, however, less clear. For example, while Scott (1986) found a negative relationship with temperature, Radun & Radun (2006) showed an increase in fatal crashes related to sleepiness and fatigue during hot weather. Reduced visibility such as during foggy conditions (Songchitruksa & Balke,

2006) and reduced daylight (Coate & Markowitz, 2004) has also been associated with increases in the number and severity of crashes. The amount of daylight has additionally been shown to be particularly important in pedestrian-related crashes where, for example, an additional hour of daylight in the USA was shown to reduce fatalities by about one-third in the early morning and by about one-quarter in the evening (Coate & Markowitz, 2004). Sunshine and wind speed are also considerations, although their effects are restricted to certain conditions. The effect of sunshine is more apparent during autumn and winter in northern countries when the sun is very low above the horizon, limiting the vision of drivers (Brijs et al., 2008) while the influence of wind speed is generally limited to large vehicles and to areas that experience extremely windy conditions (Baker & Reynolds, 1992; Levine et al., 1995).

For this study, ten measures of weather conditions were computed (Table 3.1) to represent components of weather and daylight that may be associated with the risk of RTFs. Daily data generated by the 1700 weather stations across the country were obtained from the South African Weather Service. With the exception of frost, hail, fog and snow measures that were observer-based recordings of presence or absence, the variables were continuous. For the continuous data, the average value was calculated across all weather stations within each province for each week. For the observer-based data, the number of days of occurrence of each weather type was summed for each weather station per week, and an average value was calculated for the respective province. Data on daylight was computed, based on latitude using an algorithm produced by the U.S. Naval Observatory. The measure was defined as the total time that any portion of the sun is above the horizon.

3.2.4 Public holidays

Holidays were included to account for regular calendar-related fluctuations in traffic exposure within each year. Data on holidays were obtained from the South African Government Information and Embassy web sites, and included the number of days in each week, which were part of a weekday national public holiday, a long weekend, or a school holiday (Table 3.1).

3.2.5 Statistical analysis and modelling

Using the SPSS version 14.0 (SPSS Inc.) package, univariate analysis was used to summarise the distribution of the explanatory variables listed in Table 3.1, and Kruskall-Wallis H and Mann-Whitney U tests were used to compare fatality counts across the tercile categories for the temporal explanatory variables.

Multivariable regression models were fitted to examine between-province variations in weekly RTFs. There are several models that could have been chosen for this study. Negative Binomial (NB) models were considered, but the high probability of serial correlation between variables caused us to discount them. INAR Poisson models and ARIMA models have been used extensively to study RTF data (Quddus, 2008). While INAR Poisson models are generally considered superior, particularly on low count data, there are limitations when the data displays seasonality (Brijs et al. 2008); the data used in this study has relatively high counts and significant seasonality, indicating that a model from the ARIMA family may be more suitable.

The models used in this analysis are non-linear autoregression exogenous (NARX) models. NARX models are similar to ARIMA models (Box & Jenkins, 1970) that have been employed extensively in the study of RTFs (e.g. Pulido-Manzanero et al., 2010). They contain not only autoregressive terms of the variable being studied, but also exogenous input terms that can be either autoregressive or from the present time step. In this work, NARX models were fitted to examine between-province variations in weekly RTFs using ordinary least squares regression. An expected weekly mortality count for each province, based on the annual age and sex distribution (from Statistics South Africa mid-year population estimates) of the resident population was computed, transformed into its natural logarithm, and fitted as an offset in the regression models. All continuous predictor variables were also transformed using natural logarithms, as this was found to improve model fit.

A number of statistics were calculated to ascertain the quality of the model fit and compare the magnitude of effect of the predictors. The Akaike Information Criteria (AIC) (Akaike, 1974) was used to identify the most appropriate autoregressive order of each variable, and the Durbin-Watson statistic (Durbin & Watson, 1950) was used to detect any autocorrelation in the residuals of a fitted model. Deviance statistics, calculated for the difference in -2 log-likelihood values between reduced and full models, were used to compare the magnitude of effect of the predictors. The level of significance was set at alpha=0.05 for all analyses.

The models were estimated using a backward elimination process whereby non-significant variables were removed sequentially, starting with the least statistically significant and continuing until only the statistically significant predictors remained. The models were developed using a two-stage process. In the first stage, to deal with potential problems with multicollinearity, separate regression models were fitted for variables within the three categories of explanatory variables (shown in Table 3.1). When variables were strongly collinear (identified based on r>0.3 and where the inclusion of both variables in a model resulted in parameter instability), the predictor that showed the strongest and most intuitive bivariate relationship with the dependant variable was selected. In the second stage, the statistically significant predictors from the regression models fitted to the three categories were integrated into a NARX model, these terms representing the exogenous inputs. Also integrated into the NARX model are a variable relating to long-term RTF trends (another exogenous term), and temporal autocorrelation terms in the outcome. The trend term, with sequential week values from 1-260 for the five-year study period was included, to account for any secular trend in the outcome that was not associated with the explanatory variables tested. Autocorrelation, or the serial correlation between members of a time series of observations, is an important consideration in the modelling of road crashes and injuries (Fridstrøm & Ingebrigtsen, 1991; Fridstrøm et al., 1995; Levine et al., 1995). Therefore, terms measuring the number of fatalities from the previous two weeks were included as autoregressive terms in the model.

3.3 Results

A total of 50 031 RTFs were recorded for the five years. Figure 3.1 shows the average number of weekly RTFs in provinces. It shows a general increase in fatalities until the latter part of April, followed by a general decrease until late November, along with a substantial peak in RTFs in December, with the highest values occurring in the latter part of the month (weeks 51 and 52). The December peak in fatalities was evident for each of the five years and nine provinces during the study period. Overall, the mean number of weekly deaths for December ranged from 242 in 2004 to 337 in 2006, corresponding to increases of 23.3%-

82.8%, compared with the rest of the year. The mean number of weekly fatalities for December ranged from 10 in Northern Cape Province to 57 in KwaZulu-Natal, corresponding to an excess of 96.7% and 68.8% respectively, compared with the rest of the year.

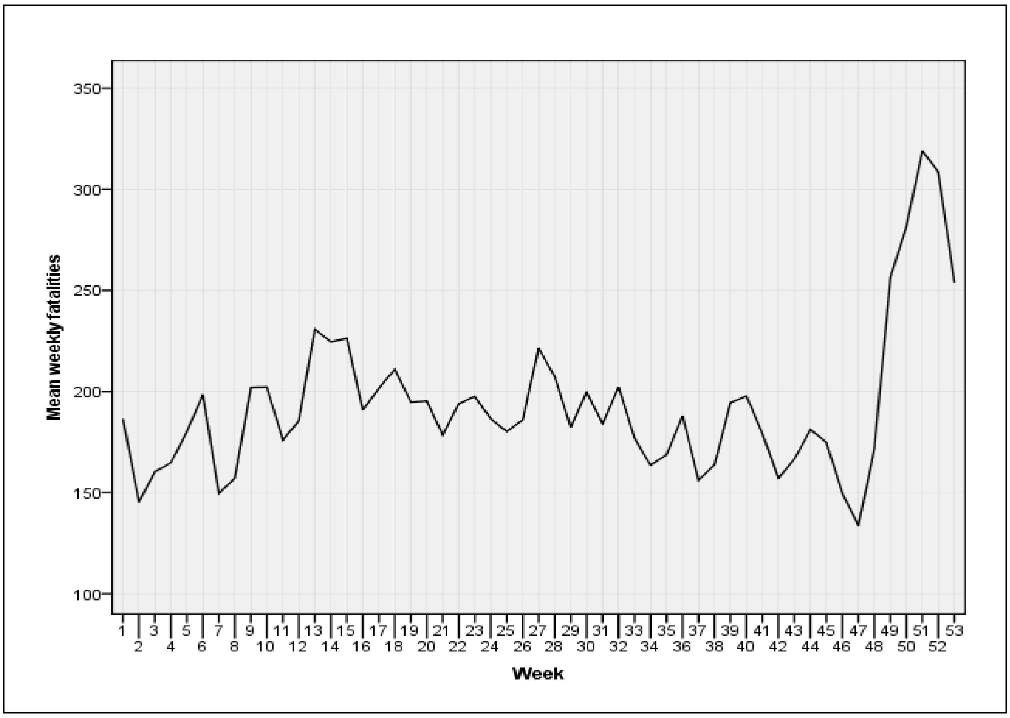

Figure 3.1: Mean road traffic fatalities by week

Table 3.2 shows the unadjusted bivariate associations between RTFs and categories of the explanatory variables. As the number of days was few, the observer-based data was converted to presence and absence for each week so as to be able to undertake comparisons. Likewise, the three public holiday measures were converted to simple categories. All temporal traffic-related variables show a clear trend of increasing risk with increasing values. The majority of the continuous weather-related measures also exhibited strong trends. The three holiday variables were related to RTFs in the direction expected, with weeks containing holidays having more RTFs.

During testing for collinearity, wind speed and frost both showed a negative relationship with the outcome variable. In the absence of evidence to support this unexpected association, the variables were not considered for multivariate modelling. Furthermore, fuel sales, driver licensing and registered motor vehicles were found to be highly correlated, and hence only fuel sales was selected for subsequent modelling.

Table 3.2: Distribution of fatalities by week and terciles of explanatory variables

Variable	Tercile or grouping category	N	Mean weekly fatalities	95% CI	*p*-value[a]
Traffic-related					
Volume of fuel (petrol and diesel) sold for road use (megalitres, 10^6 L)	1 (27.63-82.02)	779	12.27	11.73-12.81	<0.001
	2 (82.03-139.95)	778	18.83	18.25-19.41	
	3 (139.96-506.29)	783	32.98	31.94-34.02	
Population size of province (x 10^{-6})	1 (0.82-3.37)	780	13.01	12.4-13.62	<0.001
	2 (3.38-5.84)	780	18.03	17.49-18.57	
	3 (5.85-9.92)	780	33.10	32.05-34.15	
Average blood alcohol concentration (mg/100ml)	1 (48.75-95.81)	774	20.41	19.47-21.35	<0.01
	2 (95.82-110.33)	783	21.25	20.28-22.22	
	3 (110.34-303.33	783	22.47	21.47-23.47	
Number of registered motorised vehicles (x 10^{-6})	1 (0.13-0.37)	782	13.37	12.78-13.96	<0.001
	2 (0.38-0.53)	778	17.72	17.13-18.31	
	3 (0.54-2.94)	780	33.06	32.02□34.1	
Rate of driver licensing (per 100 000 Population > 14 years)	1 (1.16-1.48)	520	18.08	17.35-18.45	<0.001
	2 (1.49-2.06)	780	22.78	21.84-23.26	
	3 (2.07-3.94)	1 040	21.98	21.01-22.47	
Length of road network (10^3 km)	1 (55.01-66.40)	780	25.96	24.87-26.52	<0.001
	2 (66.41-92.18)	520	19.17	18.51-19.51	
	3 (92.19-111.35)	1 040	19.05	18.19-19.49	
Weather and daylight					
Total average daily rainfall (mms)	1 (0-1.85)	779	20.25	19.23-21.27	<0.001
	2 (1.86-10.94)	780	21.04	20.1-21.98	
	3 (10.95-95.21)	781	22.84	21.89-23.79	
Average daily maximum temperature (°C)	1 (13.77-23.54)	779	21.76	20.76-22.76	<0.001
	2 (23.55-27.60)	780	22.85	21.88-23.82	
	3 (27.61-35.82)	781	19.53	18.59-20.47	
Average daily visibility (km)	1 (15.62-26.93)	779	26.17	25.08-27.26	<0.001
	2 (26.94-32.59)	779	21.03	20.28-21.78	
	3 (32.60-43.29)	779	16.85	15.92-17.78	
Average daily sunshine (hrs)	1 (1.70-7.51)	779	23.74	22.79-24.69	<0.001
	2 (7.52-9.14)	782	20.88	19.99-21.77	
	3 (9.15-13.13)	775	19.44	18.39-20.49	
Average daily wind speed (metres/sec)	1 (6.22-9.65)	780	23.86	22.83-24.89	<0.001
	2 (9.66-11.38)	780	21.17	20.26-22.08	
	3 (11.39-17.17)	780	19.11	18.17-20.05	

Table 3.2 continued

Variable	Tercile or grouping category	N	Mean weekly fatalities	95% CI	*p*-value[a]
Total daylight (hrs)	1 (69.18-78.77)	781	21.36	20.38-22.34	0.717
	2 (78.78-90.30)	779	20.97	20.04-21.9	
	3 (90.31-100.98)	780	21.82	20.81-22.83	
Frost days[b]	Yes	873	20.90	19.98-21.82	0.144
	No	1467	21.67	20.96-22.38	
Hail days[b]	Yes	339	21.55	20.06-23.04	0.92
	No	2001	21.35	20.74-21.96	
Fog days[b]	Yes	1667	21.54	20.89-22.19	0.051
	No	673	20.98	19.88-22.08	
Snow days[b]	Yes	95	21.35	18.61-24.09	0.99
	No	2245	21.38	20.81-21.95	
Public holidays[c]					
Public holidays	0	1 917	20.78	20.17-21.09	<0.001
	1	369	23.29	21.83-24.04	
	2	54	29.57	25.11-31.85	
Long weekends	0	2 079	20.99	20.4-21.29	<0.001
	1	234	23.69	21.78-24.66	
	2	27	31.07	24.69-34.33	
School holidays	0	1 489	19.91	19.25-20.57	<0.001
	1-2	349	21.62	20.22-23.03	
	>2	502	25.59	24.21-26.96	

[a] Kruskal-Wallis H & Mann-Whitney U tests; [b] Continuous data converted to Yes/ No dichotomy (at least one event versus zero events); [c] Continuous data converted to dummy variable categories

Table 3.3: Results of NARX model

Parameter	Coefficient	95% CI	*p*-value[a]	Change in deviance[b]
Intercept term	-41.65	-50.01 - -33.28	<0.001	-
Volume of fuel (petrol and diesel) sold for road use (megalitres, 10^6 L)*	7.062	7.83 – 6.29	<0.001	304.6
Average blood alcohol concentration of traffic-related fatalities (mg/100ml)*	3.964	5.63 – 2.29	<0.001	21.6
>2 school holidays (including national public holidays) occurring over weekdays*	2.046	2.90 – 1.20	<0.001	21.8
Secular trend term: Week of study	0.0004	0.0005 - -0.0004	0.851	0.0
Autoregressive term: Fatalities from week - 1	0.3573	0.398 – 0.317	<0.001	280.6
Autoregressive term: Fatalities from week - 2	0.1439	0.183 – 0.104	<0.001	50.4

[a] based on Wald test; [b] based on the difference between -2 log likelihood values for a model without the predictor and that for the final model; * variable log-transformed

Table 3.3 shows the results from the final NARX model, showing the predictor variables that were found together to have a statistically significant relationship with weekly fatalities. The model shows that fuel sales, average blood alcohol concentration and school holidays were all statistically significant predictors of weekly variations in road traffic mortality. After accounting for the above factors, there was no evidence of a secular trend in RTFs, but the two autoregressive terms measuring fatalities in the two preceding weeks were statistically significant.

The change in deviance column shows the chi-square values that depict relative magnitude of effect of each variable, in terms of the reduction in deviance associated with its inclusion in the model. The strongest magnitude of effect is found for fuel sales and the number of fatalities in the previous week, followed by the number of fatalities at a two week lag, and then the presence of more than two school holidays in a week, and average blood alcohol concentration.

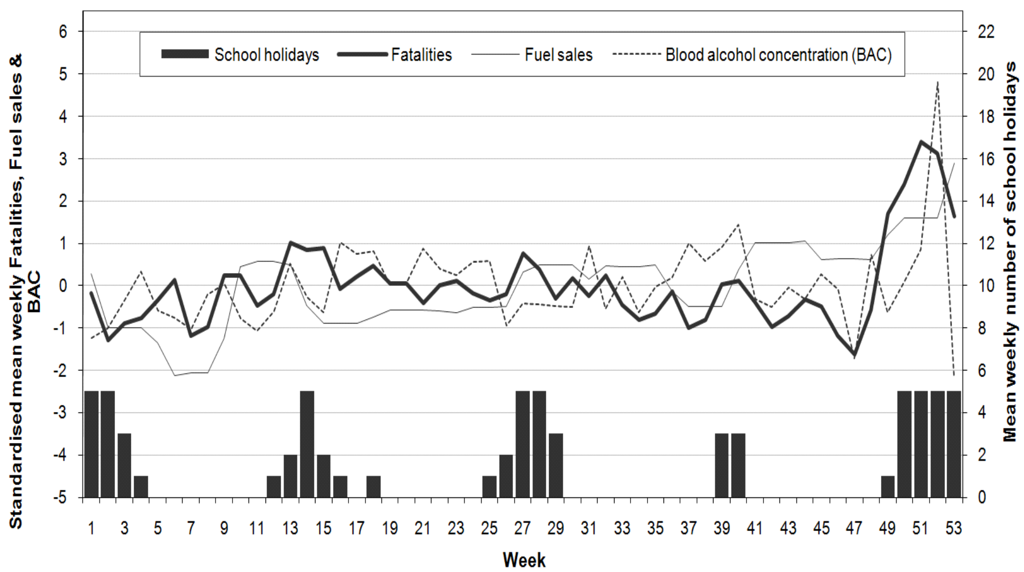

Figure 3.2: Mean weekly variation of predictors from NARX model

Figure 3.2 shows the standardised mean weekly values for the temporal predictors from Table 3.3 that were found to be statistically significantly associated with fatalities. The figure shows all predictors to exhibit a December peak; the mean weekly value for

December compared with the other months was 7.0% higher for fuel sales (p<0.01) and 12.7% higher for blood alcohol concentrations (p=0.34).

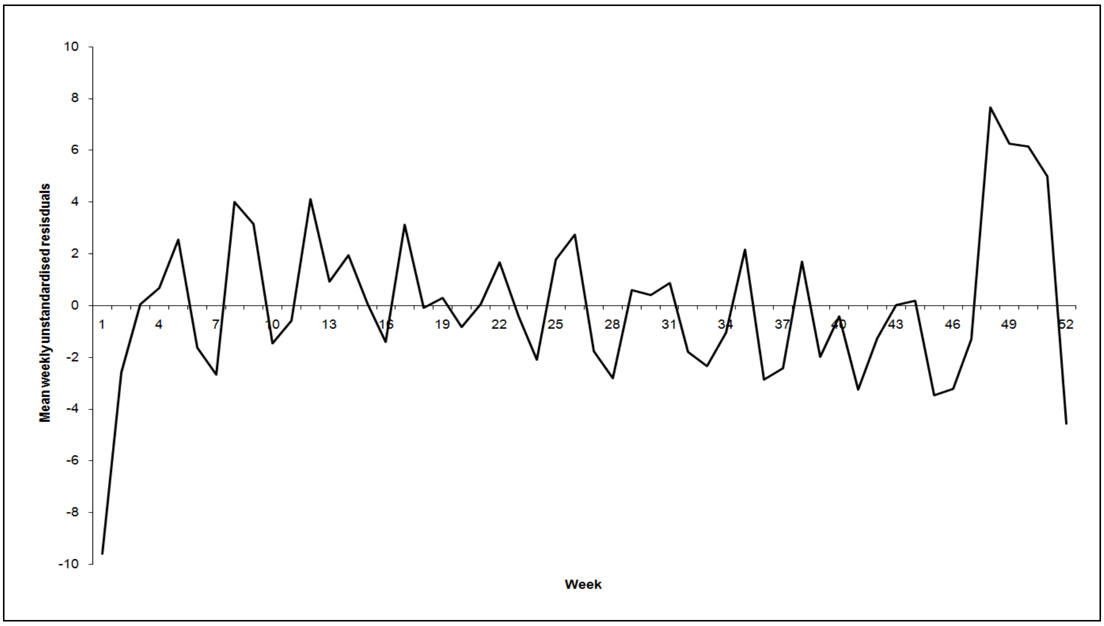

Figure 3.3: Mean unstandardised regression residuals by week

Figure 3.3 shows the mean weekly unstandardised residuals from the final NARX model over the whole study period. Compared with Figure 3.1, Figure 3.3 shows that there is still some evidence of a December peak in fatalities. Whilst this is attenuated from that present in the raw figures, its presence indicates that the excess deaths observed in this month are only partially explained by the factors included in the model.

In order to examine the degree to which the variables in the model explained previously observed geographical variations in RTFs, the mean residuals for each province were examined from a null-model, which contained only a constant term, and the final model presented in Table 3.3. Table 3.4 shows both sets of residuals, ranked in order, with negative residuals (lower than expected RTFs) appearing first. Although there was some variation in ordering of the provinces, both KwaZulu-Natal and Gauteng had higher than predicted mortality, both in the null and final models. Statistically significant between-province variation was present both in the null and final models, although unexplained variation in mortality between provinces was attenuated after control for the covariates included in the final model.

Table 3.4: Between Province residuals for null and final NARX model

	Null model				Final model		
Province	**Residual**	**LCI**	**UCI**	**Province**	**Residual**	**LCI**	**UCI**
Northern Cape	-15.80	-16.30	-15.30	Western Cape	-4.803	-5.775	-3.831
Free State	-7.112	-8.055	-6.169	Free State	-1.174	-2.102	-0.246
Limpopo	-5.662	-6.656	-4.668	Mpumalanga	-0.959	-1.974	0.056
North West	-3.473	-4.313	-2.633	Northern Cape	0.612	0.111	1.113
Mpumalanga	-2.512	-3.531	-1.493	North West	0.676	-0.181	1.533
Western Cape	-1.315	-2.292	-0.338	Limpopo	0.709	-0.245	1.663
Eastern Cape	-1.165	-2.235	-0.095	Eastern Cape	0.784	-0.181	1.749
KwaZulu-Natal	14.44	12.76	16.12	Gauteng	1.531	0.144	2.918
Gauteng	21.50	19.92	23.08	KwaZulu-Natal	2.707	1.307	4.107

3.4 Discussion

This study has shown alcohol and fuel sales together with school holidays and the number of fatalities from the two preceding weeks to be significant predictors of weekly RTFs in S.A, accounting for roughly one-third of the weekly variation in RTFs after adjustment for at-risk population sizes. Several analytical studies provide support for our finding of a significant association between RTFs and travel-related exposure (e.g. Fridstrøm et al., 1995) and with alcohol consumption (e.g. Ramstedt, 2008). It appears that higher vehicle flows and levels of alcohol consumption during the festive period at least partially underlie the particularly significant peak observed in December.

The predictors with largest effects in this study, in terms of reduction in deviance, were the measures of fuel sales and the number of fatalities from the previous week. The effect of school holidays may be a proxy for increased pedestrian counts or a component of vehicle flows not captured by fuel sales. The autoregressive term, measuring fatalities in the previous week, showed a large effect, and indicated that high or low deaths in a given week were associated with corresponding high or low values in the previous week. This may reflect that fact that we measured outcome and explanatory variables at the weekly or monthly temporal scale, whilst the actual risks associated with these change smoothly over time rather than by such discrete intervals. Alternatively, it may reflect the presence of unmeasured temporal risks that are operating at a more aggregated resolution than the week. In order to test the former possibility we fitted models in which each explanatory variable was lagged by one week (results not reported) but no lagged terms reaching statistical significance were found, suggesting the finding may more likely be due to unmeasured risks.

Residuals from the modelling exercise showed temporal variation in RTFs, especially the peak in December, to remain after adjustment. Interestingly, none of the weather-related variables were found to be predictors of weekly variations in RTFs after adjustment. This may reflect the relatively benign climate of S.A, particularly during colder months, compared with many countries in which weather has previously been the focus. Alternatively, a finer than weekly temporal scale may be needed to examine the role of weather. We believe the residual temporal variance in fatalities is most likely associated with traffic exposure. For example, over the Christmas period during December, there may be an increase in the number of unlicensed or inexperienced drivers on the road, reflecting the increased need for travel. Furthermore, a possible increase in tourism during this period may also contribute to an increase in drivers who are unfamiliar with local driving conditions. Variations in weekly RTFs between provinces were partially explained by our models, but some geographical variability remained. These findings point to the need for more detailed studies based on smaller geographical areas to better understand the geographical determinants of RTF risk in S.A.

Our research is novel in that we assembled and analysed a detailed dataset in order to understand the predictors of temporal variations in RTFs in S.A, a country in which such an analysis has not previously been attempted. However, there are a number of limitations. In terms of the measurement of travel-related exposure, we did not have information on actual vehicle flows, and therefore used fuel sales as an indirect proxy measure. There were limitations in our alcohol data as it was based on measured blood alcohol concentrations from a sample of road fatalities from which information was not available at the province level. Furthermore, the need for an adequate temporal resolution meant that we were limited in our ability to disaggregate our data geographically, and as a consequence were only able to model spatial variations in risk across the nine provinces covering S.A. Temporal information on some potentially significant risk factors, such as speeding behaviour and seatbelt usage, was not available, and we were not able to determine the impact of these risks. Furthermore, our use of records supplied by the National Department of Transport meant that we were limited to the study of fatalities. Whilst this has the advantage of minimising bias associated with under-reporting, it does mean that we were unable to determine whether patterns of non-fatal injuries mirrored those of fatalities. We only present results for all road user types, although we were able to stratify our analysis, fitting separate models for fatalities amongst vehicle occupants (drivers and passengers) and vulnerable road user groups (pedestrians and cyclists). However, the resultant models were not substantially different from those for all road users, and the results are not reproduced here.

We used a NARX approach, a variant of the commonly adopted Box Jenkins ARIMA approach (Box & Jenkins, 1970), which included weekly autoregressive, exogenous and long-term temporal trend terms in our analysis. The NARX model, like most ARIMA models, can have problems with the non-negative integer nature of RTF data, due to the normality assumption of errors with them (Sabry et al, 2007). However, we believe the advantage of being able to explicitly model the autoregressive temporal components whilst simultaneously modelling exogenous inputs from the present time step, is considerable.

Although there are only nine provinces in S.A, the study of temporal variations in RTFs at the province level is useful from the perspective that resource allocation, as well as many road safety policies and programmes such as road traffic enforcement, are province-based. In 2006, the S.A Department of Transport published a new road safety strategy, which aims to halve the number of fatalities in S.A by 2014 (NDoT, 2006). Based on the importance of travel-related exposure illustrated by our findings, reduced dependency on motorised transport especially private vehicle travel may ultimately be the most efficacious intervention. Whilst policies aimed at improving and expanding the local public transport infrastructure are supported, mass rapid transit systems including bus and rail should also be considered where possible, especially due to the country's particularly dispersed spatial structure. However, this will be difficult to achieve over the time scale of this strategy. In the short term, one of the key measures identified in the strategy relates to improving driver behaviour and in particular, improved alcohol testing and prosecutions. Our findings suggest that temporal variations in alcohol consumption are associated with variations in road traffic mortality. Given the potentially modifiable nature of this risk, we therefore suggest that initiatives targeted at drink-driving, especially in areas and at times of the year when risk is elevated, may be particularly effective.

3.5 Conclusion

Using a multivariable NARX model we have examined the factors associated with temporal variations in RTFs in South Africa. Our findings suggest that patterns are predominantly driven by temporal variations in traffic flows, although increased alcohol consumption during holiday periods may also be important. In the short- to medium-term, interventions may be most efficacious if they focus on this behavioural risk factor.

Chapter 4

Understanding geographical variations in road traffic fatalities in South Africa

Abstract

South Africa (S.A) faces an unprecedented burden of injuries from road traffic crashes, yet the distribution of these events has not yet been studied using a geographical approach in order to help understand the importance of putative social and environmental drivers. Such an approach was used in this study to investigate the correlates of spatial variations in RTFs in S.A. Variations in RTFs between 2002-2006 were studied for 993 police areas in S.A. A wide range of explanatory variables comprising physical, environmental and socio-demographic characteristics were generated, and multilevel negative binomial regression models were fitted to identify those associated with RTFs. An area measure of violence and crime was shown to be a significant predictor of RTFs in S.A with additional associations with alcohol-relatedness, travel-related exposure (from car travel), socio-economic deprivation (from the education measure), and wind speed. All these measures showed positive associations with RTFs. A negative association was found between area-based population density and RTFs. Our research provides new insight into the correlates of road traffic mortality in this less developed country, and our findings have implications for the development of integrated resource-efficient strategies that allow for enforcement and other broader structural interventions to target injuries and crime in general.

4.1 Introduction

A significant characteristic of South Africa's public health burden is the persistently high levels of injury and criminal events (Seedat et al., 2009). Currently, injuries from violence (32%) and traffic crashes (29%) are the leading causes of non-natural mortality (CVILP, 2009), and the third and seventh leading causes of overall mortality, respectively (Bradshaw et al., 2003). Based on the earlier South African (Bradshaw et al., 2003) and Global (Murray et al., 2001) Burden of Disease studies, the country's violence and road traffic fatality rates at 72.5 and 43.0 deaths per 100 000 population are disproportionately high in relation to the global averages of 14.0 and 21.6 deaths per 100 000 population, respectively.

Whilst injuries tend to be well researched and understood in many developed nations, in a less developed country such as S.A, historical social and environmental injustices provide a particular context to many social and health challenges. For example, the high rates of violence and crime, together with many of the country's poverty-related illnesses, have been attributed to its history of colonial subjugation as well as the social disruption imparted by an array of apartheid policies and practices during the past few decades (Coovadia et al., 2009; Seedat et al., 2009). The negative consequences arising from this, such as a culture of violence directed primarily against these practices, a weakened criminal justice system, and the mass removals and forced migrant labour system that weakened family systems, have also been described (Schönteich & Louw, 2001). Urban planning policies that dictated where people could and could not live resulted in a distinct and distorted spatial pattern of social and environmental risk exposure, and consequently of the occurrence of violence-related injuries and crimes. Such patterning of risks and the incidence of violence and crime is also expected to have an influence on the occurrence of RTFs. For example, road users would be expected to incur greater levels of risk exposure from the need to travel greater distances to work and to other essential services, as well as from inferior traffic and transportation systems in disadvantaged areas.

Spatial patterns in RTFs in S.A may also be directly related to the occurrence of homicide or violence-related deaths, as evidenced from international research (Porterfield, 1960; Whitlock, 1971; Holinger & Klemen, 1982; Giacopassi & Forde, 2000; Sivak, 2009). For example, Whitlock (1971) found that societies with high degrees of violence and aggression also tended to externalise this violence in the form of aggressive and high-risk driving behaviour, and this contributed to elevated rates in RTFs. In the United States, Sivak (2009) also found area variations in the homicide rate per capita to be the strongest predictor of the traffic fatality rate. This has been explained as being a manifestation of violence in societal structures whereby the same aggressive tendencies that contribute to homicides also contribute to aggressive and other high-risk driving behaviour, and consequently to road traffic collisions and injuries (Whitlock, 1971; Sivak, 2009). Perhaps equally important for the S.A context, is that elevated levels of violence and crime may also be a manifestation of generalised area and social deprivation. For example, Graham and Stephens (2008) investigated the effect of six dimensions of deprivation including a measure of violence and crime on the incidence of childhood pedestrian casualties for the wards of England, and showed the violence and crime measure to have the most consistent and compelling relationship with childhood pedestrian casualties and with children killed or seriously injured.

We suggest that the use of ecological, or area-based measures is important for understanding the role of society and the physical environment on public health conditions. Indeed, a geographical approach provides a framework to integrate the influences from both the social and physical environments, the effects of which in practice are generally impossible to dissociate (Fleury et al., 2010). Yet studies examining geographical variations in road crash risk have generally focussed on very small areas such as roads and intersections (Miranda-Moreno et al., 2007; El-Basyouny & Sayed, 2011), thus failing to capture elements of the social and environmental context that may underpin observed variations in outcomes. Whilst a number of geographical studies have been undertaken in countries of Europe (Van Beeck et al., 1991; Noland & Quddus, 2004; La Torre et al., 2007; Rivas-Ruiz et al., 2007; Jones et al., 2008; Erdogan, 2009; Spoerri et al., 2011), and in the United States (Aguero-Valverde & Jovanis, 2006), little attention has been paid to less developed nations. Whilst this reflects the more general focus of the research community, a danger is that it could cause a bias in the evidence base if it leads to an underestimation of the importance of geographical context as a determinant of crash risk. We propose that this may be possible as it could be in less developed nations where contextual influences are the strongest.

This paper seeks to contribute to the evidence base by examining the contribution of social and environmental context to observed spatial variations in road fatalities in S.A. In previous work, we have illustrated strong geographical disparities in fatalities within the country (Sukhai et al., 2009), and using a spatial-temporal framework, have highlighted the apparent importance of social factors, by showing marked temporal variations in risk throughout the year (Sukhai et al., 2010). However, to our knowledge no previous research has attempted to quantify the geographical correlates of these observed variations in road crash fatalities. In the research presented here, we adopt a geographical framework at the police area level to examine the contribution to crash risk of social factors, such as violence and crime, alongside environmental factors such as rurality in the S.A context. Whilst a range of social factors pertinent to the S.A context are considered in this research, we pay particular attention to exploring the association between road traffic, and violence- and crime-related injuries due to the particularly high death rates reported for both these injury types in the S.A context.

4.2 Data and Methods

The study was based on a cross-sectional geographical design including all RTFs reported in S.A from 2002 to 2006. Police areas, the formal policing entities of the South African Police Service (SAPS), were the lowest geographical level at which reliable data on RTFs was available, and these were used as the principal geographical level of analysis in this research. The police areas differed markedly by size; the mean police area was 1 122.4 square kilometres, ranging from 0.6 square kilometres for Wedela in North West Province to 19 550 square kilometres for Upington in Northern Cape Province. In terms of population size, the mean number of inhabitants per area was 44 586, ranging from 2 033 for Tylden in Eastern Cape Province to 429 741 for Thohoyandou in Limpopo Province.

4.2.1 Road traffic fatalities

Data on RTFs occurring across the country for the period 2002-2006 were supplied by the National Department of Transport (NDoT). The data originates from the National Traffic Information System and is based on the routine reporting of accidents by police personnel (see Appendix 1 for reporting form). All traffic-related fatalities occurring up to six days after a collision are included within the system. Police area boundaries were only available for 1997 from the Human Sciences Research Council Police Station Boundaries dataset. The boundaries were therefore updated using the Centre for Justice and Crime Prevention’s online 'South African Crime and Victimisation Mapping Tool' (http://www.cjcp.org.za), and by using historical data on changes to police stations from SAPS annual crime reports from 2002 to 2006 (http://www.saps.gov.za/statistics/reports/crimestats). Seventy police areas that were located in very rural and farming areas or at game parks were considered atypical of the rest of the country in not having a developed public road infrastructure, and hence were excluded from analyses. Police areas with less than 2000 inhabitants had wide variations in per capita deaths, and hence a further 34 were excluded. After revisions, a total of 993 police areas remained, and these were considered for analyses. Following the cross-sectional design used for this research, the RTF data were aggregated across the five-year period.

4.2.2 Explanatory variables

Explanatory variable data was obtained for times that were as temporally coincident as possible with the fatality data. Table 4.1 details the explanatory variables generated for this research. The variables were classified by nine risk categories and included measures relating to violence and crime, risk exposure, driver behaviour, characteristics of the resident population, physical characteristics of the police areas, and climate. The various sources for the data employed are indicated in Table 4.1 and in the discussion below which considers the variables that were generated. The indicated datasets from Statistics South Africa, the National Department of Transport, the South African Weather Service and the Chief Directorate: Surveys and Mapping were readily available through request, whilst data from the South African Police Services (SAPS) was obtainable through download from the SAPS website. Ethical and confidentiality agreements were not required for these data. Each variable was estimated for all included police areas using the ArcGIS 9.3 Geographical Information System (GIS) software. The variables generated for this study are described below, together with a review of the relevant literature for selected variables within each of the groups.

4.2.2.1 Measures of violence, crime and traffic offences

A combined 'violence and crime index' measure comprising murder, common assault, carjacking, and truck hijacking was computed as the number of such cases per 10 000 population and this provided a measure of 'lawlessness' and consequently a measure of social and/ or economic stress for each of the police areas. The measure is also anticipated to capture important effects from a range of aggressive and high risk driving behaviours that are well known to contribute to road traffic crashes and injuries. Alcohol misuse is also of particular importance in South Africa; RTIs was ranked third (after interpersonal violence and neuropsychiatric conditions) in terms of alcohol-attributable DALYs, accounting for 14.3% of the more than 1.1 million DALYs attributable to alcohol in 2000 (Schneider et al., 2007). In this research, data on driving under the influence of alcohol or drugs (predominantly alcohol) for police areas was used as a proxy for the levels of consumption of alcohol and drugs. The data arises from police actions at roadblocks, searches and intelligence collection, and was obtained from annual releases of national crime statistics by the SAPS (http://www.saps.gov.za/statistics/reports/crimestats). Average annual rates per 10 000 population, based on cases from 2002-2006 and 2001 census population data, were calculated.

Table 4.1: Summary of explanatory variables generated for the study

Variable description	Geographical level	Data source	Min	Max	Mean
1. Measures of violence, crime and traffic offences					
Violence and crime index measure per 10 000 population	Police area		4.26	553.46	78.95
Driving under the influence of alcohol or drug cases per 10 000 population	“	SAPS	0	114.66	8.22
% Vehicles exceeding the speed limit	Province	NDoT-Offences	24.90	59.91	42.88
% Drivers not wearing seatbelts	“	"	58.50	68.14	64.04
2. Indicators of traffic exposure					
Average monthly volume of fuel (petrol and diesel) sold for road use (megalitres)	Province	NDoT-NATIS	34.97	432.68	165.09
Average no. of driver licences issued per 1000 adult population	“	NDoT-NATIS, StatsSA	115.87	393.88	222.67
Average no. of registered motorised vehicles per capita	“	"	0.09	0.39	0.20
Average no. of bicycles per household	TAZ	NHTS	0	1.06	0.23
Average no. of motorised vehicles available for private use per household	“	"	0.02	1.91	0.46
% Households without access to a motorised vehicle for private use	“	"	3.92	97.89	72.06
3. Measures of travel-related risk (travel times in minutes)					
Average travel time to educational institutions for all modes of transport	TAZ	NHTS	13.30	60.14	28.14
Average travel time to educational institutions for users of public transport	“	"	12.50	120.00	43.92
Average travel time to educational institutions for pedestrian travel	“	"	10.00	60.98	25.15
Average travel time to work for all modes of transport	“	"	12.94	94.74	37.01
Average travel time to work for users of public transport	“	"	10.00	390.00	50.14
Average travel time for occupants of light motor vehicles	“	“	7.75	97.50	32.40
Average travel time to work for pedestrian travel	“	"	3.00	78.00	27.22
Average walking time to first transport to work and walking time at end of trip to work	“	"	1.50	51.76	13.49
Average walking time to nearest taxi stop	“	"	4.59	49.29	12.76
Average walking time to nearest bus stop	“	"	1.00	78.23	13.02
% Population attending educational institutions outside TAZ of residence	“	"	0	96.67	16.68
% Population working outside TAZ of residence	“	"	0	96.58	33.69
% Migrant workers	“	"	0	75.54	18.43
% Population that walk to work or school	Sub-place	StatsSA-CP	6.89	98.70	65.25
% Population that ride to work or school by bicycle or motorcycle	“	"	0	9.59	1.44
% Population that travel to work or school by car	“	“	0.74	86.29	19.83
% Population that travel to work or school by public road transport	“	"	0	53.42	13.47

Table 4.1 continued

Variable description	Geographical level	Data source	Min	Max	Mean
4. Socio-economic characteristics of resident population					
% Employed population with monthly income of R400 or less	Sub-place	StatsSA-CP	0	83.17	24.28
% Employed population with monthly income greater than R12 800	“	"	0	35.44	3.15
% 18-65 year old population (inclusive) with no schooling at secondary level or above	“	"	2.18	85.60	42.13
% Economically active population (15-65 years) who are unemployed	“	"	0.54	61.79	20.59
% Economically active males (15-65 years) who are unemployed	“	"	1.12	63.16	19.82
% Population living in a household with two or more people per room	“	"	0	80.27	17.41
Ratio of persons to households	“	"	1.53	7.40	3.83
% Population living in a household that is a shack	“	"	0	32.65	3.46
% Population living in a household without piped water	“	"	0	98.33	24.94
% Population living in a household without a flush toilet or pit latrine with ventilation	“	"	0	98.74	44.02
% Population living in a household without use of electricity for lighting	“	"	0	99.42	29.69
% Population living in a household without access to a telephone	“	"	0	71.99	10.77
5. Area-based measures of rurality					
% Rural population	Small area	StatsSA-SA	0	100	45.60
% Rural area	“	"	0	100	74.89
Area-based population density (SqKms)	Police area (GIS)	"	0.18	21 364.22	767.85
Person-weighted population density (SqKms)	“	"	0.29	80 683.12	3 735.03
Number of cities/towns located within police area	“	StatsSA-CP	0	2	0.16
Indicator of police area belonging to a metropolitan area	“	"	0	1	0.12
% Road length passing through urban areas	“	CD:SM	0	100	28.11
6. Land cover characteristics					
Number of educational areas per 1000 square kilometres	Police area (GIS)	CD:SM	0	12 838.02	589.49
% Area that is recreational	“	"	0	11.75	0.47
% Area that is cultivated	“	"	0	80.48	8.25
% Area that is orchard or vineyard	“	"	0	41.32	0.47
% Area that is plantation	“	"	0	57.80	1.15
% Area that is woodland	“	"	0	36.58	2.01
% Area that is vegetation	“	"	0	86.34	11.88
Herfindahl-Hirschmann Index (HHI)	“	"	132.57	10 000	6 980.67

Table 4.1 continued

Variable description	Geographical level	Data source	Min	Max	Mean
7. Road network characteristics					
Bend density (bends per km)	Police area (GIS)	CD:SM	4.24	48.08	17.93
Junction density (junctions per km)	“	"	0.14	8.46	1.80
Length of all roads (km)	“	CD:SM	8.22	3 964.02	636.39
Length of major roads (km)	“	"	0	1 200.86	162.83
% Road length classified as minor	“	"	37.26	100	77.01
8. Elevation					
Mean elevation in police area	Police area (GIS)	CD:SM	5.62	1 978.47	965.61
Standard deviation of elevation values in police area	“	"	2.03	433.80	103.79
9. Climate					
% Days with fog	Weather station	SAWS	0	28.64	3.33
% Days with frost	“	"	0	24.53	3.29
% Days with hail	“	"	0	1.10	0.09
% Days with snow	“	"	0	1.97	0.05
% Days with rain	“	"	1.31	30.23	15.07
Mean daily rainfall (mms)	“	"	0.10	4.86	1.54
Mean daily sunshine (hrs)	“	"	6.36	10.21	8.05
Mean daily maximum temperature (°C)	“	"	19.09	31.04	24.94
Mean daily minimum temperature (°C)	“	"	3.07	18.27	11.45
Mean daily visibility (kms)	“	"	7.66	79.38	28.10
Mean daily wind speed (metres/sec)	“	"	7.43	19.82	10.56

Data sources: NDoT-NATIS: National Department of Transport (National Traffic Information System).
StatsSA-CP: Statistics South Africa (Community Profiles Databases with 2001 population census data).
StatsSA-SA: Statistics South Africa (Small Area Layer with 2001 population census data).
NDoT-Offences: National Department of Transport 2003 Traffic Offence Survey.
SAPS: South African Police Services (SAPS) crime statistics, www.saps.gov.za/.
SAWS: South African Weather Service.
NHTS: National Department of Transport TRC Africa (South African National Household Travel Survey 2003).
CD:SM: Chief Directorate: Surveys and Mapping, Department of Land Affairs (1:50 000 topographical digital data).

Data on other traffic offences for this study were available at the province level from the National Department of Transport 2003 Traffic Offence Survey (DoT, 2003). Speed-related observations, based on a sample of 14978 motor vehicles, were carried out for light motor vehicles, minibus taxis and trucks in rural and urban areas, and in 60, 80, 100 and 120km/h speed limit areas. For seatbelt-wearing, the sample size was 15840 motorists, and observations were carried out in rural and urban areas by concealed observers.

4.2.2.2 Indicators of traffic exposure

Traffic volume is considered to be an acceptable measure of traffic-related exposure, and has shown to be the leading determinant of RTCIs in some settings (Lassarre, 1986; Fridstrøm et al., 1995; Haynes et al., 2008). In the absence of suitable information on traffic volumes across the country, we generated several proxy measures relating to fuel sales, driver licensing, registration and access to vehicles, and travel characteristics. Data on fuel sales, driver licensing and registered motor vehicles were available from the Department of Transport by month and for each of the nine provinces in S.A. Average monthly values based on information from 2002-2006 for fuel sales and registered vehicles and from 2004-2006 for driver licensing were calculated for each province and assigned to each police area falling within the province. Both the registered vehicle and driver licensing counts were converted into per capita figures according to the size of the resident adult population aged over 14 years from 2004 and 2005 mid-sample population estimates from the S.A Census. Additional vehicle-related measures on household access to motorised running order vehicles for private use and household bicycle ownership was extracted from the South African National Household Travel Survey 2003 database, available from the Department of Transport. The vehicle access measure included vehicles owned by households, by relatives/friends, and by employers. Data was available for 342 National Travel Analysis Zones (TAZs) that cover the whole country, and the values for each TAZ were assigned to police areas that fell therein.

4.2.2.3 Measures of travel-related risk

Distance travelled is a commonly used indicator of exposure to the risk of traffic crashes (Jovanis & Chang, 1986; Fridstrøm et al., 1995), hence average travel times, based on the 2003 South African National Household Travel Survey, were calculated for various modes of travel (light vehicles, public transport and pedestrian) and various destinations (work, educational institution and transport terminals). Additional mobility measures of the proportion of the population that travel outside the police area for work, education and migrant travel were calculated. Migrant workers were defined as 15 years and older who were employed, and had another place in South Africa regarded as home.

The final set of travel exposure measures was the proportion of the population that travelled to work or school using various modes of transport. Data for these measures was obtained at the census Sub-place level from the Statistics South Africa Community Profiles Database. Sub-places represent the second lowest census level (after Enumerator areas) and may include suburbs, sections of townships, smallholdings, villages, sub-villages, wards or informal settlements (StatsSA, 2004). There was a total of 21 243 Sub-places, and the ArcGIS package was used to allocate them to the police areas using their geographical centre-points, and a mean value for each of the police areas was calculated.

4.2.2.4 Socio-economic characteristics of resident population

Several area and social deprivation indicators have been shown be associated with the occurrence of RTFs, with a general higher probability of accident-involvement being associated with lower socio-economic status (Borrell et al., 2005; Rivas-Ruiz et al., 2007; Spoerri et al., 2011). For this study, a range of socio-economic deprivation measures was considered. Data for these measures were obtained at the census Sub-place level from the Statistics South Africa Community Profiles Database, and population percentages were calculated and assigned to the police areas. For income, both a low and a high threshold value for the gross income before tax was considered, based on the 12 categories of income available from StatsSA. The lower monthly income value of R400 is consistent with the StatsSA poverty line of R431 (approximately $40) per capita for 2006. The higher threshold value was used to reflect on the top 5% of the employed population earning a monthly income greater than R12 800 (approximately $1300). Education deprivation was represented by the 18-65 year population that did not have a secondary school education. Indicators for overcrowding included the ratio of persons to households, and the percentage population living in a household with two or more people per room, a threshold often used as an indicator of crowding (Bhorat et al., 2004). Socio-economic measures that reflect local area deprivation included a measure of the population living in informal shack dwellings and four measures relating to access to basic municipal services.

4.2.2.5 Area-based measures of rurality

Rurality is an important area-based dimension to the geography of RTFs, although one that may be difficult to define (Sukhai et al., 2009). To encapsulate and understand the complex notion of rurality in this analysis, seven measures of rurality were included. The calculation of four of these measures has been described previously (Sukhai et al., 2009) and included the percentage of the population living in rural areas, average population size, crude population density, and person-weighted population density. The influence of large urbanised centres was assessed by calculating the number of cities/towns located within the police areas using the geographical centre-points of cities and towns, and by establishing whether the police area belonged to one of the six metropolitan areas in the country. The effect of urban roads was included using road length data from the 2006 Chief Directorate: Surveys and Mapping 1:50 000 topographical data. The percentage of the police area roads that passed through census-defined urban areas was also calculated.

4.2.2.6 Land cover characteristics

The effect of various land uses on regional variations in RTFs has not been well studied, but some prior research points to higher traffic crashes closer to commercial areas than to residential areas (Kim & Yamashita, 2002). Hence the Herfindahl-Hirschmann Index (HHI) (Song & Rodriguez, 2005), based on the Chief Directorate: Surveys and Mapping 1:50 000 topographical dataset, was calculated to provide a measure of the mix of land uses within the police areas. The HHI for this study was based on vegetation, recreation and parks, high urban density and low urban density land uses, and calculated as the sum of the squares of the percentages of each of the land uses included. The higher the value, the lower the levels of land use mix, such that, were there only one land use present in a police area, the value of the HHI would be 10 000.

4.2.2.7 Road network characteristics

For our study, data for all functional categories of roads used for vehicle travel were extracted from the Chief Directorate: Surveys and Mapping 1:50 000 topographical dataset. The ArcGIS package was used to allocate the road line data to its respective police area. For calculations, all residential access roads and streets were considered to be minor roads, and the remaining (comprising national, arterial, major, main and secondary roads) were considered to be major roads. Based on area level studies, there is some evidence for road curvature being protective at the district level in England and Wales (Haynes et al., 2007), although other studies have shown an absence of effect in New Zealand (Haynes et al., 2008) and the USA (Noland & Oh, 2004). In our study, the curvature of the roads in each police area expressed as the number of bends per kilometre of road length, and the number of junctions per kilometre of road length, were both computed in the GIS using the methodology of Haynes et al. (2007).

4.2.2.8 Elevation

The role of elevation in the geographical variability in RTIs has previously been examined for local authority districts in England and Wales (Jones et al., 2008). Although no association was found in that work, elevation may be an important variable in the South African context owing to its diverse topography, characterised by large mountainous landscapes. Digital elevation data at a 400m resolution for most areas and at 200m for urban and mountainous areas was obtained from the Chief Directorate: Surveys and Mapping. Both the mean elevation and standard deviation, to measure variability, were calculated for police areas.

4.2.2.9 Climate

In the context of geographical variations, there is prior evidence for a positive relationship between precipitation and RTF risk (Aguero-Valverde, 2005; Aguero-Valverde & Jovanis, 2006). South Africa is diverse with notable variability in weather patterns found across the country. For this analysis, 11 climate-related measures were calculated for the police areas to identify aspects of climate that may be associated with variations in RTFs. Daily weather data was obtained from the South African Weather Service for approximately 1700 weather stations from 2002-2006. Observer-based data on the presence of fog, frost, hail and snow was expressed as the percentage of days that the phenomenon was recorded for at least one weather station in the police area. The remaining variables were average daily values across all weather stations within the police areas. For rainfall, both the percentage of days with rain and the average daily rainfall values were included.

4.2.3 Statistical analysis and modelling

Multilevel negative binomial regression models were fitted to examine the variations in the counts of RTFs between the police areas. The negative binomial count model was used to accommodate over-dispersion in the dependent variable. A two-level structure was employed to account for the nesting of police areas within the country's nine provinces, and the models were fitted using the MLwiN package for multilevel modelling (Rasbash et al., 2009). Model coefficients were estimated by restricted iterative generalised least squares (RIGLS) with second order predictive/penalised quasi likelihood (PQL) approximation. RIGLS was used because when the level 2 units are few, as with this analysis, it provides less biased estimates of the variance than alternative estimation strategies (Rasbash et al., 2009). Expected mortality counts for each police area were computed based on national age and sex-specific mortality rates and Statistics South Africa mid-year population estimates for police areas; and the expected count for each area was transformed into its natural logarithm and fitted as an offset in the regression models. The natural logarithm transformation was also used for continuous predictor variables where transformation showed an improvement to model fit.

The estimation of R^2 goodness of fit statistics is not possible from multilevel models, because the unexplained variance is explicitly modelled. Furthermore, the derivation of R^2 values from negative binomial regression models is inexact and dependent on the method used. Therefore, to provide an indication of model goodness of fit, R^2 values were obtained using a non-multilevel OLSs algorithm in MLwiN, using the logarithm of the police area Standardised Mortality Ratios (SMR) as the dependent variable.

The regression models were fitted using a backward elimination process whereby non-significant variables were removed sequentially starting with the least statistically significant and continuing until only the statistically significant predictors remained. The models were developed using a two-stage process, similar to that employed previously (Sukhai et al., 2010). In the first stage, to deal with potential problems with multicollinearity, separate regression models were fitted for variables within the nine categories of explanatory variables shown in Table 4.1. When variables were strongly correlated (identified based on $r > 0.3$ and where the inclusion of both variables in a model resulted in parameter instability), the predictor that showed the strongest and most intuitive bivariate relationship with the dependent variable was selected. In the second stage, the statistically significant predictors from the regression models fitted to the nine categories were integrated into a multiple regression model. Other uni- and bivariate statistical analyses were undertaken using SPSS version 14.0 (SPSS Inc.). The level of significance was set at alpha=0.05.

4.3 Results

The mean number of RTFs for the police areas was 50.4, ranging from 1 in 29 police areas to 392 for Rustenburg in North West Province. Figure 4.1 shows the geographical distribution of the crude road traffic fatality rates per 100 000 population. The figure shows concentrations of police areas with high population-based fatality rates in the South West and North East parts of the country.

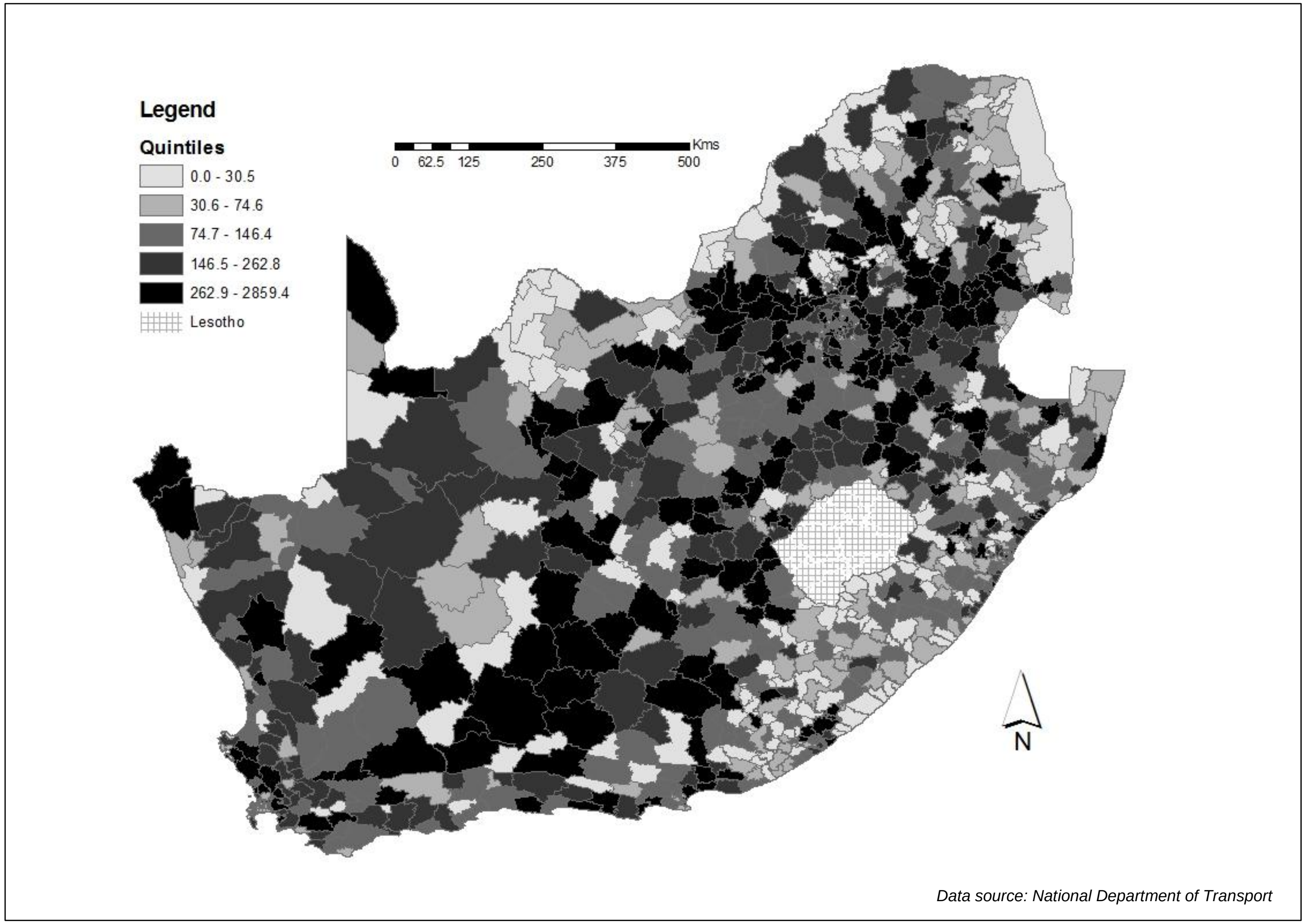

Figure 4.1: Road traffic fatality rates per 100 000 population for police areas

Table 4.2 shows the results from the final multilevel negative binomial regression model, showing the 6 predictor variables that were found together to have a statistically significant relationship with the number of RTFs for the police areas. Both the violence and crime and the DUI measures showed a statistically significant relationship with RTFs. In addition, statistically significant associations were apparent for the travel exposure, education deprivation, population density, and wind speed measures. The directions of effect for the predictors were all consistent with that expected. With the exception of population density, the coefficients were positive, suggesting an increase in RTFs with increasing values for these variables. Also shown in table 4.2 are the standardised coefficients, provided to show the relative magnitude of effect size of each of the predictor variables in the model. The strongest magnitude effect was found for population density, followed by similar sized effects for travel exposure, violence and crime, and DUI offences. Smaller effects were found for education deprivation and wind speed. When estimated as an OLS model, an adjusted R^2 value of 0.25 was obtained, indicating that one-quarter of the variation in RTFs between police areas was explained by the explanatory variables included in the model.

Table 4.2: Significant predictors of RTFs from negative binomial multilevel model

Parameter	Coefficient	SE	Standardised beta coefficient	*p*-value
Intercept term	-2.3070	0.6056	-	<0.001
Violence and crime per 10 000 population*	0.3305	0.0488	0.5279	<0.001
Driving under the influence of alcohol or drug cases per 10 000 population	0.0177	0.0027	0.4292	<0.001
% Population that travel to work or school by car*	0.2708	0.0489	0.5419	<0.001
% 18-65 year old population with no schooling at secondary level or above	0.0075	0.0032	0.2539	0.020
Area-based population density (Sq Kms)*	-0.2424	0.0182	-1.1571	<0.001
Mean daily wind speed (metres/sec)*	0.4458	0.2123	0.1341	0.036

* Variables transformed to natural logarithms

Figure 4.2 shows the geographical distribution of the unstandardised residuals from the final negative binomial multilevel model. The figure shows that after accounting for the effects of the variables in our model, the distribution of the residuals does not show evidence of any notable geographical pattern.

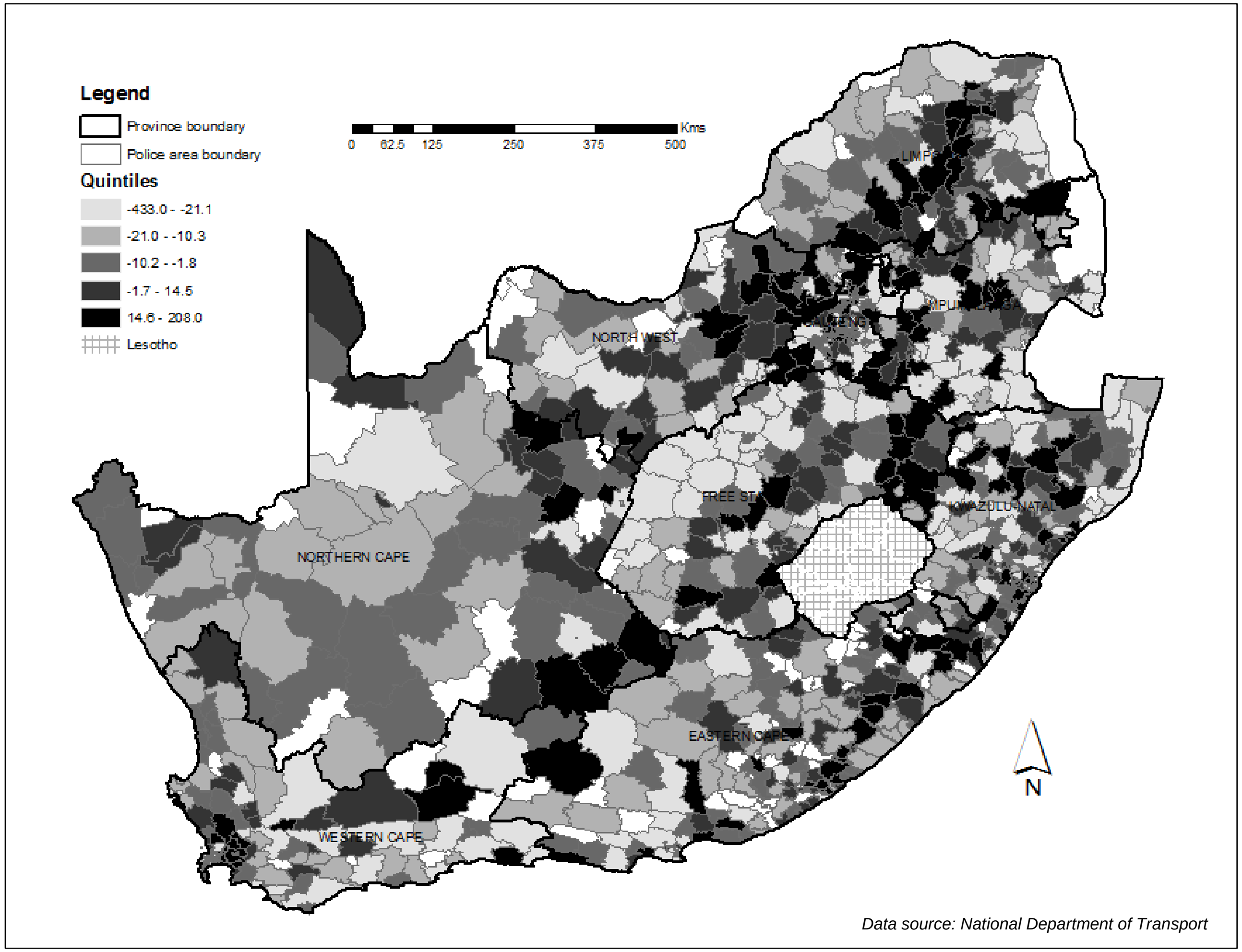

Figure 4.2: Residuals from multilevel negative binomial model for police areas

4.4 Discussion

Our study has shown that a number of social and environmental variables are associated with the geography of RTFs in S.A. It is noteworthy that we found a positive association between RTFs and cases of violence and crime in South Africa, as evidenced by both a general 'violence and crime index' measure and a DUI measure. The finding is consistent with those from previous studies (Porterfield, 1960; Whitlock, 1971; Holinger & Klemen, 1982; Giacopassi & Forde, 2000; Graham & Stephens, 2008; Sivak, 2009). The association with DUI has also been reported from other geographical studies on road traffic mortality such as for Spain at the province level (Rivas-Ruiz et al., 2007) and Italy at the regional level (La Torre et al., 2007).

A further two population-based and two area-based measures were also shown to be significant predictors of geographical variations in RTFs. The area-based population density measure showed the largest association with the geographical variability in RTFs. Population density was inversely related to the geographical variations in RTFs, suggesting higher levels of fatalities in rural areas. This is consistent with findings from a number of other studies on the geography of RTFs (Thouez et al., 1991; Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011). The relatively high burden of RTFs in rural areas has been shown to be associated with more severe collisions and injuries (Thouez et al., 1991; Scheiner & Holz-Rau, 2011). Alcohol-related crashes have also been shown to be more prevalent in rural areas (Besag & Newell, 1991; Levine et al., 1995; Czech et al., 2010).

The percentage of the population travelling to work or school by car showed a positive association with RTFs, illustrating the likely role of exposure. It is noteworthy that this measure of vehicle-related travel was a stronger predictor of RTFs than a range of other measures included in the study, including some such as fuel sales, road lengths and travel times that have been shown to be significant in other studies.

Our education deprivation variable showed a positive association with RTFs, and findings from several studies support this association with deprivation (Borrell et al., 2005; Rivas-Ruiz et al., 2007; Factor et al., 2008; Spoerri et al., 2011). The precise mechanisms are not clear, but characteristics of deprived areas are expected to predispose road users, particularly pedestrians and children, to RTIs. In general, individuals in more deprived police areas are more likely to need to walk to meet their basic transportation needs, thereby increasing their traffic-related exposure and elevating their risk from greater mobility (Sonkin et al., 2006) or from the need to cross roads more often (Macpherson et al., 1998). The elevated risk to road users in deprived areas may also be due to possible effects of inferior traffic infrastructure and traffic and transportation systems. A relatively greater use of unsafe and poorly maintained vehicles, or engaging relatively more in unsafe driving practices such as not using safety belts, helmets and child-safety seats than in other relatively more affluent areas may also contribute to the elevated risk to road users in more deprived police areas (Babio & Daponte-Codina, 2006).

In the absence of other associations with weather, the statistically significant association observed with wind speed was unexpected, because other weather-related variables tested, particularly precipitation, may be expected to be more strongly associated with RTFs based on findings from other geographical studies such as at the county level in Pennsylvania (Aguero-Valverde & Jovanis, 2006) and in analyses for the greater Nordic countries (Fridstrøm et al., 1995) and for the United States (Eisenberg, 2004). The effect for wind speed did not seem to be related to other variables in our study. We cannot explain this unexpected association based on our available data and suggest that wind speed may be proxying the effects of other measures not included in this study.

Given the context of the South African setting to this work, our finding of an association between RTFs and our measure of crime and violence has particular implications. The persistently high rate of injuries and crimes in general, almost two decades after the country's transition into democracy, suggests that the country is still far from being a healthy society. It is important that the underlying structural factors that underpin injuries and crimes in general, especially the expansion and strengthening of strategies to address the strong influences of substance abuse and poverty, be aggressively targeted. It may be that targeting skills development and employment strategies for priority unemployed groups will be important in addressing poverty and at the same time, one could also expect declines in injuries and crimes from individuals being kept away from antisocial behaviour and from reducing their levels of mobility and traffic-related risk exposure.

The key road-based policy recommendations based on these results centre on the development of ways by which to reduce dependency on motorised transport in the long term, but to address drink driving violations through improved enforcement of driver behaviour in the short term. In addition to expansion, current enforcement strategies should also be optimised. For example, strategies targeting DUI are generally concentrated only during the popular holiday seasons, and testing is conducted only on drivers showing overt signs of intoxication. Current levels of aggressiveness and disregard for laws may also relate to tainted perceptions of enforcement, resulting from a history of enforcement that focussed on the policing of apartheid laws and the protection of white people. Hence, strategies should also take cognisance of this sensitivity to policing and should as far as possible incorporate elements of police marketing to increase buy-in from the public on the acceptability of enforcement.

Our study has a number of strengths and weaknesses. It is, to our knowledge, the first study that has attempted to explain geographical variations in RFTs in South Africa, using a range of detailed variables generated in a Geographical Information System. The variables we have generated cover a wide range of domains of potential risk factors. Our analyses were also undertaken at a relatively fine geographical scale, whilst previous descriptive work has focussed on geographical distributions by the country's nine provinces (RTMC, 2010); and we used a robust statistical methodology.

Limitations with our data centre on under-reporting of road traffic deaths in police records, and with our data being restricted to fatalities. Under-reporting is expected to be a bigger problem in rural than in urban areas owing to general limitations on resources in rural settings, and this may have introduced an element of geographical bias in the analyses. Similarly, one may expect the geographical distribution of non-fatal injuries to be significantly different to that of RTFs, but, with being limited to data on fatal RTIs only, we were unable to explore associations for non-fatal crashes. Whilst we incorporated a large range of variables to explain the geographical variations of RTFs in South Africa, this meant that we undertook many statistical comparisons; some of the associations we have observed may be the result of multiple testing. With using a cross-sectional design, we are also restricted to pointing to associations between RTFs and our explanatory variables; stronger analytical designs will be required to ascribe causality.

Some potentially important risk factors could not be considered owing to lack of suitable data being available at a national level. These include: the design and layout of roads

(Wright & Robertson, 1976), access to advanced pre-hospital and hospital trauma care that may mediate the elevated risk in rural areas (Baker et al., 1987; Van Beeck et al., 1991), and socio-cultural differences in norms and expectations of various social groups that may manifest in different risk-taking levels and consequent involvement in road traffic crashes (Factor et al., 2008). Additionally, the influence of commercial land use such as employment density (Graham & Glaister, 2003; Noland & Quddus, 2004) and of other traffic generators such as major shopping centres were not included; these may be considered in future research. The Department of Transport traffic offence and some traffic exposure variables did not reach statistical significance in our models, and this may be because they were only available at the coarse province level. Should finer scale data become available, it should be employed in future research. In our analysis we had information on the place of collision but not on the place of residence for each victim. Whilst this allowed us to investigate many attributes of the physical environment, an implication is that our social measures may not reflect those of the victim's area of residence, although Haynes et al. (2005) showed collisions to be more related to conditions where the collision occurs than where the victim lives.

4.5 Conclusion

Using a negative binomial multilevel model within a geographical framework, we examined the role of a range of factors on the occurrence of RTFs in S.A at the police area level. Of particular relevance to the setting, our findings show violence and crime to be a significant predictor of RTFs in South Africa. Furthermore, geographical variations in RTFs were also associated with factors measuring driver behaviour, traffic exposure, and socio-economic deprivation. Short- to medium-term interventions should focus on broad-based inter-sectoral enforcement strategies that would allow for targeting antisocial behaviours in general, including those from adverse driving and violence and crime-related behaviour.

Chapter 5

Urban density, deprivation and road safety: A small area study in a South African metropolitan area

Abstract

Given the significant challenges facing many cities, such as from urbanisation and other urban processes, and especially in low- to middle-income country contexts, city focussed studies provide an important platform for exploring small area geographical variations in road traffic injuries (RTIs). The South African setting provides a particularly useful context for such enquiry given the large extent of socio-spatial disparities and deprivation, arising especially from historical apartheid-related policies and practices. Following a paucity of small area research on RTIs, particularly in the South African setting, this study examined small area variations in RTIs for the eThekwini Metropolitan Area (comprising predominantly the City of Durban). Population density was used as an organising framework within which to examine variations in RTI outcomes and correspondence, with a range of measures relating to characteristics of the crashes, and to socio-economic deprivation. Analyses were undertaken at the suburban level, using data from 2005-2009 and employing a cross-sectional geographical design. Analyses were also undertaken for disaggregated injury, crash severity, and road user groups. A general inverse relationship was found between RTIs and population density for fatal and non-fatal injuries. The higher injury rates in low density rural areas were associated with higher values for proxy measures relating to inappropriate or excessive driving speeds, excessive travel exposure, and general social as well as area level deprivation. Higher levels of crash severity were associated with higher levels of cases occurring over weekends, involving public transport vehicles, and also with area level deprivation. Findings from the predictive models showed population density to be a significant predictor of all injury outcomes but the effects of population density could only partially be explained by the crash and socio-economic measures included in the study. The findings on deprivation provide new insight into rural-urban variations in RTIs, at least for the South African setting. The findings also have implications for informing integrated developmental policies and strategies across a range of disciplines and departments, especially at the city level.

5.1 Introduction

The occurrence of RTCIs is particularly sensitive to the effects of population density (Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011). This may be especially apparent for cities and other urban centres that are subject to disparate as well as changing levels of population density such as through urbanisation and other related processes of suburbanisation and urban sprawl. For the first time in history, since 2007, the majority of the world's population is living in cities and other urban centres. Whilst an increasing trend of urbanisation is forecast, with six out of every ten people living in towns or cities by 2030, the urban population of developing countries is expected to double between 2000 and 2030 (WHO, 2010).

Cities generally hold promise of prosperity, offering better opportunities for income generation, quality housing and living conditions, and access to services such as education, health care and social support (WHO & UN-HABITAT, 2010). However, with rapid rates of urbanisation, municipalities struggle to cope with the provision of essential services and infrastructure, such that opportunities are unevenly distributed and are often accompanied by major challenges to the health and safety of vulnerable populations. Particularly in less developed countries, the increasing densities of urban areas, especially from the growth and influx of poor populations, results in an "urbanisation of poverty" (Ravallion et al.,2007) and inequity that manifests as a multitude of deprivations, and commonly associated with informal settlements and other housing deprivation. These populations also find themselves at increased risk to a triple threat of infectious diseases from overcrowded conditions, non-communicable diseases owing to unhealthy urban lifestyles, and injury-related disorders (WHO & UN-HABITAT, 2010), as well as perinatal and maternal disorders (Mayosi et al., 2009). The challenges facing cities have received global attention in recent years, with the World Health Organisation dedicating World Health Day 2010 to urban health and calling upon municipal authorities and other stakeholders to examine and take action on the health inequities in cities (WHO, 2010a; WHO, 2010b).

Deterred by the negative aspects of city life, there is also the movement of people away from the city, such as by those more affluent members of the population seeking suburban lifestyles. Such movement contributes to urban sprawl with low density and fragmented forms of development that threaten the efficient use of urban infrastructure and services

(UN-HABITAT, 2009). Consequently, there has been increasing attention on the rising urban population densities in many parts of the world (Newton, 2010; Ng, 2010). General arguments for a more compact urban form through densification point to environmental and financial sustainability of cities, economic growth and employment through the spatial concentration of firms, and economic and social inclusion from better access to opportunities (Turok, 2009). Whilst density is a product of the physical housing structures as well as the resident population, the key objective of densification strategies is to raise population densities (Turok, 2009).

Levels of urbanity or rurality, as influenced by urban processes such as those discussed above, has been shown to be an important discriminator to the geographical distribution of risk exposure and the occurrence of RTIs, along with contributory influences of the social and physical environments. For instance, evidence focussed on regions, provinces or states across countries have shown a consistent inverse association between death from road traffic crashes and population density, which is commonly used to proxy the effects of rurality or urbanity in coarse-scaled geographical analyses (Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011). For example, Noland & Quddus (2004) in a study of 8414 wards in England, showed urbanised areas with higher densities to be associated with fewer casualties (especially fatalities), but also that areas of higher employment density to be related to more casualties. The authors used negative binomial count models to control for a range of area level factors including land use types such as population density, road characteristics such as the number of roundabouts and junctions, demographic characteristics such as deprivation, and proxies for traffic flow such as measures of employment. Similarly, Spoerri et al. (2011), in a geographical study of RTFs at the municipality level in Switzerland, found road traffic mortality to increase with decreasing population density, but this was only true for the motor vehicle occupant road user group. The inverse relationship between population density and death from RTIs has also been shown for the South African setting in a coarse-scaled geographical analysis of RTFs that examined a large range of social and environmental influences across police areas in the country (Sukhai & Jones, 2013). In this study, population density was also shown to be the strongest predictor of the geographical variations in RTFs. The reasons for these effects have, however, not been investigated for the South African context.

The high burden of road traffic deaths in low density rural areas, and predominantly in HICs, is often attributed to poorer injury outcomes owing to inadequate access to quality pre hospital and advanced in-hospital trauma care (Baker et al., 1987; Van Beeck et al., 1991) and relatively higher levels of risky driving behaviour such as drinking and driving, excessive driving speeds and non-wearing of seatbelts (Besag & Newell, 1991; Dumbaugh & Rae, 2009; Strine et al., 2010). For example, Van Beeck et al. (1991) showed that in the Netherlands, advanced trauma care (neurosurgery and computerized tomography (CT-Scan)) along with traffic density, were the most important predictors of regional variations in traffic mortality, with both variables showing an inverse relationship with case fatality (ratio of traffic deaths to injured people). In terms of risky driving behaviour, Strine et al. (2010) examined self-reported seat belt use across the United States by adjusting for seat belt law and several other factors such as socio-demographic characteristics, and found that respondents in the most densely populated metropolitan areas were significantly more likely to report always wearing seat belts compared with those in the most sparsely populated rural areas (adjusted odds ratio = 2.9).

Certain population and road user groups tend to predominate in crashes and injuries in low density rural areas due largely to differential exposure to risks such as those described above. In terms of road users, the evidence from several geographically based studies on traffic crashes and injuries points to higher fatal injuries in rural areas for vehicle occupants (Chen et al., 1995; Muelleman & Mueller, 1996; Spoerri et al., 2011) and higher pedestrian risk and injury in urban areas (Petch & Henson, 2000; Scheiner & Holz-Rau, 2011). With child pedestrians, the risk of injury has been shown to be far greater in urban than in rural areas (Petch & Henson, 2000; Scheiner & Holz-Rau, 2011) as well as among socio-economically disadvantaged population groups (Christie, 1995). For example, the risk of a pedestrian-related crash for children living in urban areas was reported to be around five times higher than for those living in rural areas (Petch & Henson, 2000). Whilst the elevated risk to child pedestrians is likely to be the result of area level infrastructural factors, injury-related crashes involving older pedestrians have been shown to be directly related to the availability of alcohol through bars (LaScala et al., 2000).

By virtue of the heterogeneous landscapes within cities, we suggest that the effects of population density on health and safety, and in particular its influences on various road traffic outcomes, may be more apparent for small areas within cities and other urban centres, and thus provide a useful context for understanding small area geographical influences on road safety. Small areas are generally taken to comprise geographical classifications below the level of health or local authority district, commonly wards or groupings of enumeration districts (Carstairs, 1981) in the United Kingdom, or to counties and sub-county areas such as cities, census tracts, ZIP code areas, or individual blocks (Murdock & Ellis, 1991) in the United States. Small areas tend to display greater social homogeneity compared with census level administrative units, and thus are regarded as more suitable units of analysis in epidemiology (Carstairs, 1981; Haining et al., 1994; Haynes et al., 1999). For example, Haynes et al. (1999) compared a range of social and demographic predictors of crash rates in pre-school children using census enumeration districts, wards and specially constructed social areas, and found specially constructed small areas to yield the best fitting models.

Consistent with a paucity of small area studies on RTFs internationally, to the best of our knowledge, small area studies of RTIs have not been conducted in South Africa. Small area and city-focussed studies are important for the South African traffic context for at least three reasons that are also somewhat interrelated.

First, geographical variations in health and safety conditions are largely related to socio-spatial patterns arising from historical urban planning policies under the apartheid regime, that dictated where people could and could not live (see Coovadia et al., 2009; Seedat et al., 2009 for further detail). Whilst the general increased traffic-related risk exposure to populations in widely deprived communities from greater mobility (Sonkin et al., 2006), from the need to cross roads more often (Macpherson et al., 1998), and from relatively greater use of unsafe and poorly maintained vehicles, and from engaging in unsafe driving practices (Babio & Daponte-Codina, 2006), have been described in other settings, these and other socio-spatial and related deprivation type risks that are particular to many cities and other urban centres in the country have not been examined in relation to the occurrence of RTIs in the country.

Second, large-scale migration of deprived populations to urban and urban fringe areas is characteristic of many large cities. Poor living conditions within informal settlements, arising from rural-urban migration, often exacerbate the social and economic stress to migrants and pose further traffic-related challenges, especially with inadequate pedestrian-related traffic facilities, and the need for them to interact with relatively complex traffic systems (see Ribbens et al., 2008 for further discussion).

Third, South African cities typically show large variability in population densities arising from the combined processes of urbanisation with pockets of informal settlements close to the city, urban sprawl with low density developments in some suburban areas, and historical forced removals with high population density township developments on the outskirts of the city. However, the effects of such disparate population densities on the health and safety of affected populations are generally unknown.

Given the distinctive processes and challenges to road safety within cities as well as the general paucity of empirical research in this area, this study seeks to contribute to our understanding of the geography of RTIs in South Africa by examining small area variations in RTIs and their influences for the eThekwini Metropolitan Area (EMA, incorporating the city of Durban). The imperative for small area focussed studies within cities is also highlighted when considering the general preoccupation by South African government policy and politics in rural challenges and development (Boraine, 2011), and the progressive devolution of built environment functions to metropolitan areas in the country (SACN, 2011). The EMA is characterised by high levels of socio-economic and spatial disparities and injuries (eThekwini Municipality, 2011; SAMRC-UNISA CVILP, 2005), providing a relevant test bed from which to explore small area variations in RTIs. Following the significant influences of population density on RTCIs, found especially in coarse-scaled studies, population density is used as an organising framework in this research so as to explore the population density influences on RTIs, and help elucidate some of the possible drivers to these relationships at a small area level.

5.2 Methods

The study was based on a cross-sectional geographical design at the suburban level for the EMA. Suburbs, contained within cities and other urban centres, are not part of the census geographical hierarchy, but rather, they represent city planning and service-delivery units. In displaying greater social homogeneity compared with census areas, suburbs may be regarded as relatively more appropriate entities for research on injury prevention and safety promotion. In order to reduce the effects of random year-to-year variation, aggregated data over the five-year period were used.

5.2.1 Study setting

The setting for this study is the EMA, which is one of eight metropolitan areas in South Africa and is located in the province of KwaZulu-Natal. The EMA covers a land area of approximately 2 300 square kilometres and is home to some 3.5 million people. In addition to large urban centres, the EMA also contains large tracts of rural areas. Based on census classification, only 35% of the land area is considered predominantly urban, with more than 80% of the population living in these areas (eThekwini Municipality, 2011). The Statistics South Africa census definition of urban and rural areas is based on the dominant settlement type and land use within Enumerator Areas (EAs), which is the lowest geographical level used for non-population based census dissemination (StatsSA, 2003; StatsSA, 2004). Typical urban settlements are cities, towns, townships, and suburbs, whilst rural areas typically tend to contain tribal areas, commercial farms and rural informal settlements (StatsSA, 2004). With an annual average economic growth of 3.7% from2004 to 2009, compared with 3.4% for the province and 3.3% for the country (eThekwini Municipality, 2011), the economy of the EMA may be regarded as relatively progressive.

Despite a progressive economy, however, the EMA is also characterised by increasing levels of poverty and inequality, as well as by having the highest rate of unemployment of all metropolitan areas in the country. In 2004, estimates indicated that 31% of the population were living in poverty, 34% were unemployed, and the Gini coefficient, a measure of inequality ranging from 0 (perfect equality) to 1 (perfect inequality), was at 0.60 (Dray et al., 2006). The Inanda/ Ntuzuma/ KwaMashu complex (INK) in the Metro is also one of 7 urban and 22 total presidential poverty nodes that represent the largest concentrations of poverty in SA and that are earmarked for accelerated development (DPLG & Business Trust, 2007). As a result, the EMA also contains some pockets of extreme deprivation.

5.2.2 Data for road traffic injury and explanatory variables

Table 5.1 details the measures relating to injury outcomes, crash characteristics, and socio-economic deprivation considered for this study. Aggregated suburb level data on RTIs and crashes were provided by the eThekwini Transport Authority (ETA) for 2005-2009. Data from the ETA were based on ‘accident report’ forms completed by police personnel as well as reports made to the police by members of the public involved in road traffic crashes (see

Appendix 1). In terms of fatal injuries, cases with death occurring up to six days after a collision are considered by the ETA. Injuries requiring hospitalisation were considered serious injuries. Population-based fatal and serious injury rates were considered for analysis. Following the particular area level risks for pedestrian injuries such as inadequate infrastructure for crossing or separation from motorised traffic, analyses are also undertaken separately for the pedestrian road user group. Population density for our study was based on population counts from the 2001 census, which was the latest census data available.

To determine the role of characteristics of the crashes, especially as a proxy for high-risk driving behaviour, measures relating to time and day of occurrence, road surface condition, type of crash, and type of vehicle were included as percentages in the study. As with many other countries, transport-related injury in the country shows distinct temporal patterns. For example, based on the 2010 findings from National Injury Mortality Surveillance System that has full coverage of fatal injuries in Gauteng (a predominantly urban province) and Mpumalanga (a predominantly rural province), 40% of cases occurred during the evening peak from 18h00-00h00, and roughly 40% of cases also occurred over the weekend (Saturday and Sunday) (SAMRC-UNISA SAPPRU, 2012a; SAMRC-UNISA SAPPRU, 2012b). However, a greater proportion of evening cases (38% vs. 36%), and of weekend cases (45% vs. 40%) was recorded for the rural province of Mpumalanga than for Gauteng.

In terms of road surface condition, the effect of wet road surfaces from rainfall was considered. Detailed analyses of rainfall and road crash data, for example that undertaken for the USA and Israel, have shown the added risk of injury crashes in rainy conditions to be substantial, being two to three times greater than in dry weather, which may be even greater when rain follows a dry spell (Brodsky & Hakkert, 1998). In terms of the type of crash and vehicle involved, the evidence points to a preponderance of certain crash and vehicle types in certain settings and among certain population groups, such as speed-related single vehicle crashes among young drivers (Chen et al., 2009) or higher injury severity scores for pedestrian injuries involving sport utility vehicles and pick-up trucks (Ballesteros et al., 2004). The above risks are also expected to vary with population density and rurality. For example, high-risk driving behaviour such as drinking and driving, excessive driving speed, and non-wearing of seatbelts have been described as contributors to findings of relatively higher injury rates in low density rural settings than in urban settings (Besag &

Newell, 1991; Dumbaugh & Rae, 2009; Strine et al., 2010). Several crash types are considered that may proxy the above high-risk driving behaviour, such as single vehicles that overturn or crashes occurring with fixed objects. In terms of vehicle type, a relatively higher involvement of large trucks in rural crashes has been described in other settings such as the United States (Muelleman & Mueller, 1996; Lyles et al., 1991).

Strong evidence supports the general finding of higher crashes and RTIs with lower socio-economic status for coarse-scaled analyses at the police area level in South Africa (Sukhai & Jones, 2013), as well as in other international settings (Borrell et al., 2005; Rivas-Ruiz et al., 2007; Spoerri et al., 2011). The 22 presidential poverty nodes comprise 7 urban and 15 clusters across the country (DPLG & Business Trust, 2007) indicating that the effects of deprivation are not exclusive to rural or urban areas. In order to explore associations and to understand possible mechanisms involved with deprivation, four socio-economic deprivation measures relating to both poverty and area level deprivation were obtained from the Statistics South Africa Community Profiles Database and considered for this study. The measures included the influences of informal shack dwellings, education, employment and income. The population living in informal shack dwellings was included, so as to capture influences of area level deprivation. Education deprivation was represented by the 18-65 year population that did not have a secondary school education. The unemployed population was considered from the sub-set of the economically active population (15-65 years). Finally, the income measure was based on the 12 categories of income available from StatsSA. Taking into account the income categories, a monthly income value of R400 that is consistent with the StatsSA poverty line of R431 per capita for 2006 was used in order to capture levels of poverty.

In order to assess the effects of the proximity of major roads to the suburb of occurrence on RTIs, demarcated national freeways and main roads were included, using the 2006 Chief Directorate: Surveys and Mapping 1:50 000 topographical data. Major roads represent relatively high traffic volumes and high driving speeds, both being widely accepted as contributors to exposure and risk of crashes and RTIs (Lassarre, 1986; Fridstrøm et al., 1995).

5.2.3 Assigning road traffic injury and explanatory data to suburbs

Boundary data for the suburbs were obtained for planning units that are utilised by the municipality for management and service delivery. The boundaries of the planning unit areas matched those of the suburbs closely, and they comprised census Sub-places and Main Places or combinations of both. Sub-places and Main Places represent the second- and third-lowest census levels after EAs (StatsSA, 2004). Sub-places generally include suburbs, sections of a township, smallholdings, villages, sub-villages, wards or informal settlements, while Main places generally include cities, towns, townships, tribal authorities and administrative areas (StasSA, 2004). Hence, areas from the non-census suburb classification may straddle both Main place and Sub-place census levels, especially in the case of towns, townships and informal settlements. The municipal boundary data were then adapted (mostly through renaming and merging some areas) and integrated with the suburb level traffic data from the ETA within a Geographical Information System (GIS) using the ArcGIS 9.3 GIS software. Five of the suburb areas, which were demarcated to an expanded area of the EMA in 2001 (eThekwini Municipality, 2002), did not have data available. A total of 68 remaining suburbs were considered for analyses. The suburbs differed markedly by size; the mean area was 30.0 square kilometres, ranging from 2.2 square kilometres for Canelands in the North to 160.6 square kilometres for the Adams/ Folweni/ Sobonakhona cluster in the South.

The Small Area Layer, created by combining all EAs with a population smaller than 500 with adjacent EAs within a Sub-place, is the lowest geographical level for which population data are available (StatsSA, 2005). Since the boundaries for census areas are only partially coincident with that of the suburbs, the ArcGIS package was used to allocate the Small Areas (and their population counts) to the suburbs using their geographical centre-points. Likewise, socio-economic deprivation measures at the census Sub-place level were also allocated to the suburbs. The ArcGIS package was also used to integrate the road line data for the major roads within the GIS.

5.2.4 Calculation and expression of outcome and explanatory measures

Injury severity was considered using population-based fatality rates, calculated by dividing the number of cases for the suburbs by the respective population exposed, and expressed as the number of deaths per 100 000 population. Crash severity, expressed as the quotient of the combined fatal and serious injuries, and the total number of collisions, and measures relating to characteristics of the crashes were also expressed as percentages. Both crude and person-weighted population density measures were calculated within the GIS and considered for the analyses. Weighted population density was considered to accommodate possible effects of population clustering. The crude measure was the quotient of the total population and land area in square kilometres, which was then weighted using the Small Area Layer to produce the person-weighted measure. However, the measures showed similar geographical distributions to each other and were also highly correlated (0.81, $p<0.001$), and consequently, only the crude population density measure that showed a general stronger correlation with the injury outcomes was considered for the analyses.

Following the lack of a convincing linear relationship between population density and RTIs, evidenced at the coarse-scaled DC census level across the country using several exposure-based indicators (Sukhai et al., 2009), the relationships with population density in this study were explored using quartiles, in addition to linear correlation. Population-based rates for the injury outcomes and explanatory measures were calculated separately for each of the population density quartiles. Finally, population percentages were calculated for the socio-economic deprivation measures, and were assigned to the suburbs.

5.2.5 Statistical analysis

Using the IBM SPSS Statistics version 19 software, univariate analysis was used to summarise the distribution of the outcome and risk-related variables listed in Table 5.1. The Pearson's correlation coefficient and P-value was calculated to test the strength in the relationship between variables.

The software was also used to undertake linear regression analyses to test for linear trend across quartiles for the different measures, and to model the predictors of the road traffic outcomes for the EMA. To identify the presence of linear trend across the population density quartiles, the slope lines for the rates and proportions for the injury outcomes and explanatory measures were examined and tested, if their fitted lines were significantly different from zero. For the predictive modelling, negative binomial models were fitted for the four outcome measures, using the natural logarithmic transformation of the population size variable as an offset. The negative binomial count model was used to accommodate over-dispersion in the dependant variable. Only variables showing a statistically significant association with the respective outcome measures were included in the models. For similar measures within the day, time and social deprivation groups, only those which contributed best to model fit were selected from each group. The regression models were fitted using a backward elimination process whereby non-significant variables were removed sequentially, starting with the least statistically significant, and continuing until only the statistically significant predictors remained.

5.3 Results

A total of 3 199 fatal and 20 509 serious injuries were recorded for the 68 suburb areas included in the study over the five-year period from 2005-2009. The overall average annual rate per 100 000 population for the EMA, based on the 68 suburbs, was 21.2 for fatal injuries and 135.9 for serious injuries. On average, 3.5% of road crash victims sustained fatal injuries and 15.8% sustained serious injuries. On average, there were also 0.1 fatal or serious injuries per road traffic collision.

Table 5.1 shows the leading day for crashes to be Saturdays, accounting for nearly one-fifth of all crashes. Nearly one-quarter occurred at night and nearly one-fifth during the evening peak hour period from 4-6pm. About one-tenth occurred when the road surface was wet. Crashes occurring whilst turning, and with a fixed roadside object, were the most common type of crash, accounting for about 10% each of all crashes. More than half the vehicles involved in the crashes were cars, followed by roughly one-fifth light delivery vehicles. In terms of the socio-economic deprivation, on average for the suburbs, little under one-fifth of the population have less than a secondary level of education, and the same proportion are unemployed. Of those that are employed, about two-thirds earn a monthly income of R400 or less.

The average population density across the suburbs was 2 053.7 persons per square kilometre (S.D. 2 284.2), ranging from 18.5 to 10 225.8. Figure 5.1 shows the geographical distribution of the population density measure. The distribution shows a fragmented spatial form with three clusters of suburbs with very high population densities: the city centre and surrounding suburbs (central East coast of city); the northern township areas, including much of the INK complex and Phoenix; and township areas in the south, including Umlazi and Chatsworth.

Table 5.1: Summary of explanatory measures

	Min	Max	Mean
Crash characteristics			
Day of week			
% Saturday	0.00	100.00	17.94
% Sunday	0.00	28.95	12.83
Time of day			
% Night	0.00	37.84	24.40
% Twilight	0.00	25.00	10.19
% Morning peak (6-8am)	0.00	25.00	12.62
% Evening peak (4-6pm)	6.25	100.00	17.08
Road condition			
% Wet road surface	0.00	25.00	12.36
Crash type			
% Head-on	0.00	4.11	0.94
% Single vehicles overturned	0.00	100.00	6.08
% Vehicle- animal	0.00	20.00	2.56
% Vehicle- fixed object	0.00	50.00	10.24
% Turning	0.00	18.98	10.84
Vehicle type			
% Car	0.00	73.99	55.03
% LDV	0.00	38.46	18.95
% Minibus taxi	0.00	100.00	13.64
% Bus	0.00	7.69	1.81
% Medium/ heavy commercial	0.00	27.27	3.29
% Articulated	0.00	36.54	3.15
Socio-economic deprivation			
% Population living in a shack	0.00	31.61	3.73
% Population with less than secondary level education	0.00	37.65	16.55
% Population who are unemployed	0.00	33.42	15.86
% Population with monthly income of R400 or less	0.00	88.59	65.00

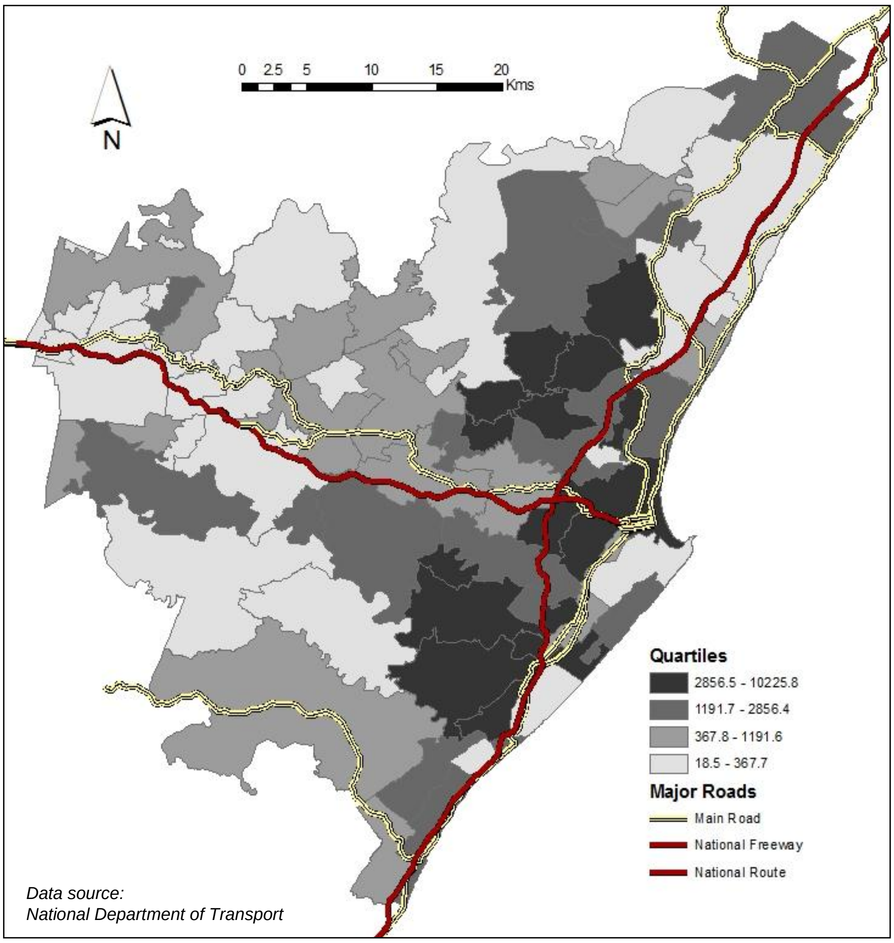

Figure 5.1: Population density of EMA suburbs

Figures 5.2 and 5.3 show the geographical distribution of rates per 100 000 population over the five-year period for fatal and serious injuries, respectively. The figures show a similar distribution in the quartiles for both injury outcomes, with some concentration of suburbs with high rates along the East coast and the central to Western parts of the EMA. The figures also show the network of major roads that tend to shape the distribution of RTIs in the EMA. The major roads comprise the N2 and M4 freeways that run largely along the East coast, and the N3 and M13 freeways that traverse in an East-West direction.

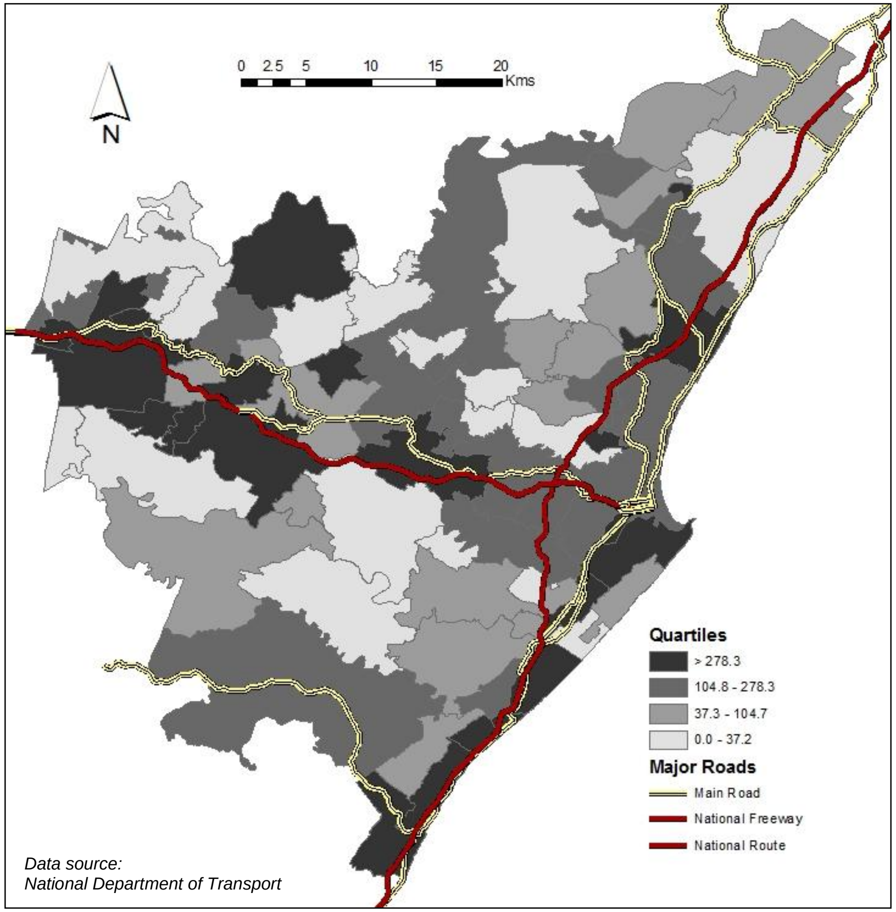

Figure 5.2: Overall fatal injury rate per 100 000 population (2005-2009)

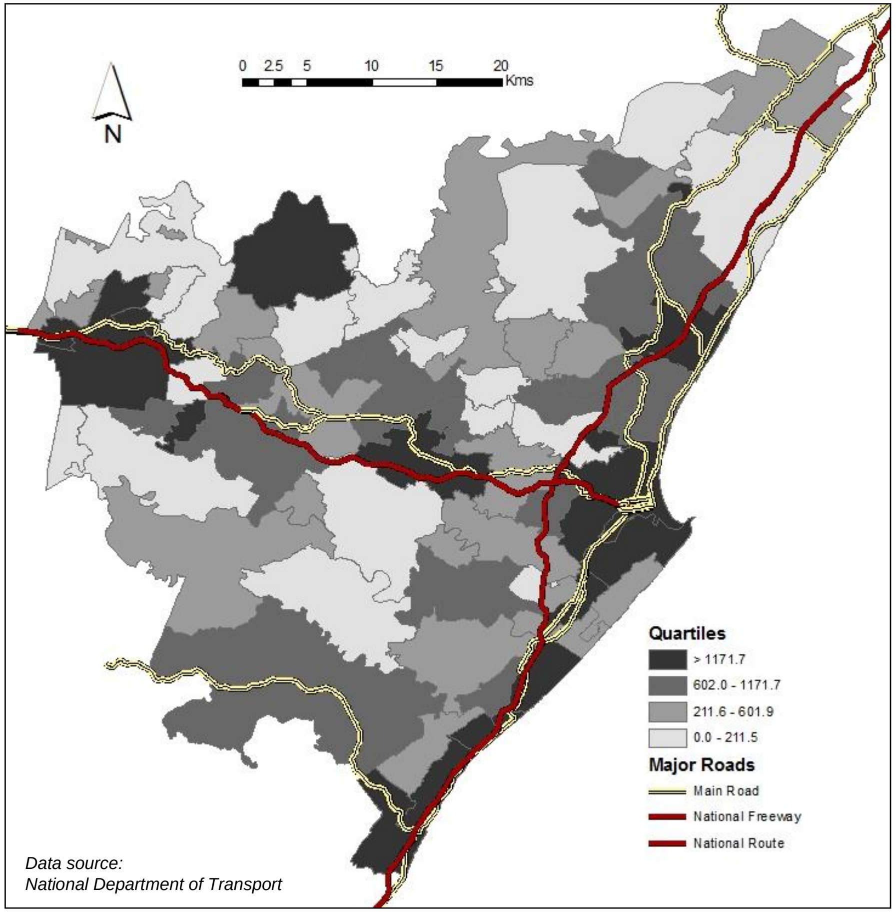

Figure 5.3: Overall serious injury rate per 100 000 population (2005-2009)

Figure 5.4 shows the linear relationship between the overall and pedestrian-related rates for fatal and serious injuries, with mean confidence intervals. The figure shows strong linear associations of the injury rates between the road user groups, indicating similar patterns in their geographical distributions.

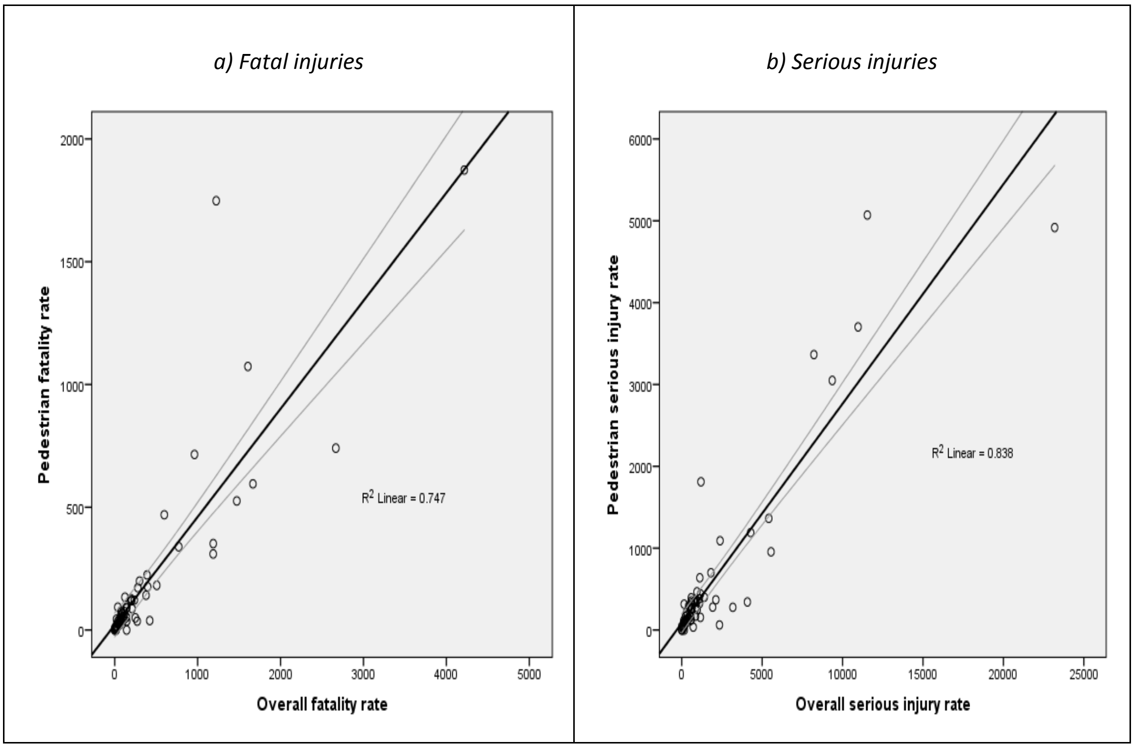

Figure 5.4: Relationship between overall and pedestrian rates for fatal and serious injuries

Figure 5.5 shows the geographical distribution of the crash severity measure. The map shows a different pattern to the geographical distribution of the fatal and serious injury rates. Distinct concentrations of suburbs with high levels of severity are evident in the Northern, and Western to South-western parts of the EMA.

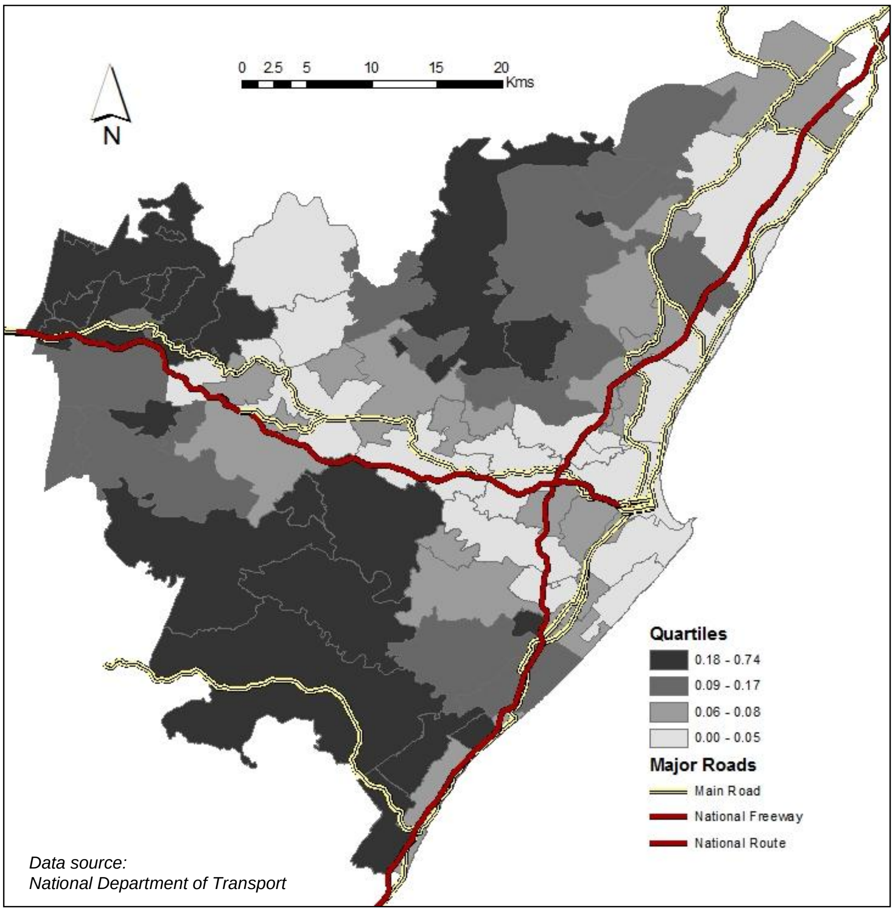

Figure 5.5: Crash severity index (2005-2009)

Table 5.2 shows the relationship between the RTI outcome measures, and the measures of crash characteristics and of socio-economic deprivation, by quartiles of population density. Only the measures of the percentage of articulated vehicles, and the percentage of vehicle-animal crashes, showed a statistically significant linear trend by the quartiles of population density, both decreasing with increasing population density. Other patterns in the measures by quartiles of population density are, however, evident. In terms of fatal injuries, Table 5.2 shows the lower density quartiles (Quartiles 1 and 2) to have higher rates per 100 000 population compared with the higher density quartiles (Quartiles 3 and 4) for both the overall and pedestrian injury groups. The above pattern is also evident for serious injuries in the overall injury group. With serious injuries in the pedestrian group, a less clear differential is evident with population density, with high rates in the relatively low density Quartile 2 as well as in the highest density Quartile 4. For the crash severity index, the highest ratio was evident in the highest density Quartile 4. Following the general inverse patterns above, statistically significant negative correlations were found between population density and the rates for overall fatalities (r=-0.32, p=0.01), pedestrian fatalities (r=-0.29, p=0.02), and overall serious injuries (r=-0.27, p=0.03).

Table 5.2: Injury outcome by quartiles of crude population density

	Quartile 1 (18.5-367.7)	Quartile 2 (367.8-1191.6)	Quartile 3 (1191.7-2856.4)	Quartile 4 (28656.5-10225.8)	P-value
Injuries					
Rate of fatal injury per 100K population*	274.25	237.69	71.52	80.79	0.08
Rate of pedestrian fatal injury per 100K population*	109.44	144.06	45.80	53.53	0.27
Rate of serious injury per 100K population*	1250.22	1116.15	334.27	727.91	0.27
Rate of pedestrian serious injury per 100K population*	243.99	448.30	145.10	415.38	0.81
Crash severity index	0.068	0.062	0.066	0.078	0.36
Crash characteristics					
Day of week					
% Saturday	13.38	12.21	15.03	16.22	0.17
% Sunday	9.67	8.24	10.38	11.65	0.27
Time of day					
% Night	20.54	18.21	21.06	20.68	0.67
% Twilight	8.64	8.66	10.03	9.49	0.25
% Morning peak (6-8am)	11.57	13.08	14.56	12.30	0.63
% Evening peak (4-6pm)	16.70	16.74	16.83	16.12	0.34
Road condition					
% Wet road surface	12.86	13.28	12.66	10.06	0.20
Crash type					
% Head-on	0.45	0.40	0.61	0.50	0.48
% Single vehicles overturned	2.75	2.29	2.39	0.68	0.14
% Vehicle- animal	1.12	0.81	0.77	0.29	0.047
% Vehicle- fixed object	7.56	8.09	8.90	5.49	0.52
% Turning	11.66	14.49	14.92	14.13	0.31
Vehicle type					
% Car	58.95	58.75	61.91	60.42	0.34
% LDV	17.19	17.53	18.45	14.86	0.49
% Minibus taxi	5.59	8.02	7.44	14.03	0.13
% Bus	1.30	1.48	1.59	2.64	0.12
% Medium/ heavy commercial	3.91	3.99	3.10	2.49	0.07
% Articulated	9.51	7.08	3.53	1.80	0.01
Socio-economic deprivation					
% Population living in a shack	2.10	1.55	4.49	6.17	0.09
% Population with less than secondary level education	22.47	17.37	17.32	15.21	0.09
% Population who are unemployed	18.45	16.90	19.48	19.52	0.39
% Population with monthly income of R400 or less	77.21	68.29	71.18	68.63	0.29

* 5-year rate (2005-2009)

In terms of crash characteristics, the higher injury rates in relatively low density areas, specifically in quartiles from 1-3, are also shown to be accompanied by higher percentages of collisions involving single vehicles that overturned, animals, and fixed objects, that occurred on a wet road surface, and that involved medium/heavy and articulated commercial vehicles. The highest levels of crash severity in Quartile 4 show to be accompanied by higher percentages of cases occurring over weekends (on Saturday and Sunday) and with vehicles involving buses and minibus taxis.

In terms of socio-economic deprivation, the relatively higher injury rates in low density areas, specifically in Quartile 1, show to be accompanied by higher percentages of the population that have less than a secondary level of education, and by the percentage of income earners that receive a monthly income of R400 or less. Relatively higher percentages of the population that live in shack settlements are shown to be more evident in the higher density quartiles 3 and 4, showing some correspondence with both the high rates of serious injury rates for the pedestrian group, and the crash severity index in Quartile 4. The measure for the percentage of the population that were unemployed did not show a notable differential by population density.

In contrast with patterns in the measures by quartiles of population density, Table 5.3 shows the statistically significant associations between the five injury outcome measures, and the explanatory measures that were considered for analysis. Only explanatory variables showing a significant association with at least one injury outcome measure are indicated in the table.

In terms of crash characteristics, the fatal and serious injury rates for the overall and pedestrian injury groups showed statistically significant negative correlations, with the percentage of crashes occurring on a Sunday, and strong positive correlations (ranging from r=0.7 to r=0.8) with the percentage of cases involving articulated heavy vehicles. The crash severity measure showed statistically significant positive correlations with the percentages of crashes that occurred on a Sunday, that occurred at night, that included collisions with involving animals, and that involved LDV and buses. The crash severity index measure also showed statistically significant negative correlations with the percentages of crashes that occurred on a wet road surface, that involved turning-related crashes, and that involved cars.

In terms of socio-economic deprivation, the pedestrian-related fatal and serious injury rates showed statistically significant positive correlations with the measure for the percentage population living in shacks, and statistically significant negative correlations with the measure of the percentage population with a monthly income of less than R400. The income measure was also negatively correlated with the overall serious injury rate. The income measure, as well as the measures for the percentage population with less than secondary level education and the percentage population who were unemployed showed statistically significant positive correlations with the crash severity index measure.

Table 5.3: Significantly associated injury outcome and explanatory measures*

	Overall fatality rate	Ped. fatality rate	Overall serious injury rate	Ped. serious injury rate	Crash severity index
Crash characteristics					
Day of week					
% Sunday	-0.24 (0.05)	-0.25 (0.04)	-0.26 (0.03)	-0.24 (0.05)	0.43 (<0.01)
Time of day					
% Night	-0.12 (0.33)	-0.19 (0.11)	-0.19 (0.11)	-0.22 (0.07)	0.45 (<0.01)
Road condition					
% Wet road surface	0.02 (0.87)	-0.01 (0.97)	-0.05 (0.71)	-0.08 (0.51)	-0.27 (0.03)
Crash type					
% Vehicle- animal	-0.09 (0.49)	-0.13 (0.30)	-0.11 (0.39)	-0.12 (0.31)	0.39 (<0.01)
% Turning	0.11 (0.36)	0.15 (0.21)	0.16 (0.20)	0.22 (0.08)	-0.32 (0.01)
Vehicle type					
% Car	-0.11 (0.37)	-0.09 (0.47)	-0.12 (0.32)	-0.09 (0.45)	-0.40 (<0.01)
% LDV	-0.05 (0.67)	-0.06 (0.66)	-0.08 (0.51)	-0.07 (0.59)	0.46 (<0.01)
% Bus	-0.21 (0.08)	-0.15 (0.23)	-0.14 (0.26)	-0.09 (0.47)	0.31 (0.01)
% Articulated	0.82 (<0.01)	0.75 (<0.01)	0.83 (<0.01)	0.66 (<0.01)	-0.16 (0.19)
Socio-economic deprivation					
% Population living in a shack	-0.01 (0.93)	0.29 (0.02)	0.12 (0.33)	0.26 (0.03)	-0.10 (0.43)
% Population with less than secondary level education	-0.15 (0.23)	0.02 (0.87)	-0.11 (0.37)	-0.05 (0.66)	0.42 (<0.01)
% Population who are unemployed	-0.20 (0.10)	-0.09 (0.48)	-0.19 (0.12)	-0.12 (0.32)	0.29 (0.02)
% Population with monthly income of R400 or less	-0.38 (<0.01)	-0.32 (0.01)	-0.40 (<0.01)	-0.37 (<0.01)	0.47 (<0.01)

* Only explanatory variables with significant association with at least one injury outcome measure are included; statistically significant associations are shaded

In order to explicate some of the effects arising from population density, and based on the data available, Table 5.4 compares the coefficients for population density from an unadjusted and an adjusted model that includes other significant effects, with the four count-related outcome measures considered for this study. Of note is that, although the effect of population density is attenuated in the adjusted models due to the effects of other explanatory variables that explain the outcomes, the effect of population density is still statistically significant along with these effects.

Table 5.4: Population density effect from unadjusted and adjusted models for injury outcomes

	Unadjusted model				Adjusted model			
	Coefficient	Standardised coefficient	S.E	P-value	Coefficient	Standardised coefficient	S.E	P-value
Fatal injury	-0.000319	-0.012931394	0.000044	<0.001	-0.000204	-0.008269606	0.000055	<0.001
Fatal pedestrian injury	-0.000246	-0.013483808	0.000046	<0.001	-0.000134	-0.007344838	0.000056	0.017
Serious injury	-0.000259	-0.001280163	0.000045	<0.001	-0.000183	-0.000904517	0.000059	0.002
Serious pedestrian injury	-0.000151	-0.001001969	0.000047	0.001	-0.000138	-0.000915707	0.00005	0.006

Along with population density, statistically significant effects also included: percentage of crashes involving fixed objects (for all injury outcomes); percentage articulated vehicles (for all injury outcomes except pedestrian serious injury); percentage of minibus taxis (for overall and pedestrian fatal injuries); percentage of crashes occurring during afternoon peak hours, and percentage unemployed population (both for overall serious injuries); and lastly, the income deprivation measure of percentage population earning less than R400 (for serious pedestrian injury).

5.4 Discussion

The EMA showed a generally low population density, with substantial variation in values across suburbs. Distinct patterns were found for the geographical distribution of RTIs in the EMA, and a general inverse relationship was found between population density and RTIs for most outcome measures. The similarity in the distribution of fatal and serious injury rates as well as for the pedestrian user group is notable, given the general paucity of geographical research focussed on differences in road user groups and on non-fatal injuries. Several measures relating to characteristics of the crashes, and to measures of socio-economic deprivation showed to correspond with the injury outcome measures. In addition, population density showed as a significant predictor of all injury outcomes. That population density was significant along with other measures included in this study, suggests that other measures not considered in this study may also explain the effects of population density. The key findings are discussed below, along with findings from previous research.

5.4.1 Population density and RTIs

An inverse relationship between population density and RTIs was found for the overall fatal and serious injury rates, and for fatal injuries in the disaggregated pedestrian injury group. Given the particular challenges and processes within cities such as those arising from urbanisation, this is an important finding that confirms the general negative association between population density and RTIs (in particular fatalities), commonly found for large geographical areas (Thouez et al., 1991; Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011) also to manifest at the small area level, as shown at the suburb level for the EMA. The consistency in findings for the varying injury severity and road user groups also points to the influential role of area level effects on RTCIs. In contrast with the population findings from this research, crude population density did not show as a reliable measure of rurality in previous rural-urban analyses at the DC census level (Sukhai et al., 2009). This may, however, be due to the DC geographical units being more likely to contain clusters of populations that are relatively more heterogeneous in nature and bigger in physical size than the suburban small areas used in this study.

Exceptions to the inverse pattern were for serious injuries in the pedestrian injury group, and for the crash severity index. For serious injuries in the pedestrian group, high rates were found in areas with relatively low population density (Quartile 2) as well as in areas with high population density (quartile 4). The presence of relatively higher pedestrian injury rates in urban areas has been documented previously, although mostly for fatal injuries (Spoerri et al., 2011; Petch & Henson, 2000). The relationship with serious injury may stem from a combination of relatively higher pedestrian-related activities with relatively lower speeds in high density urban areas. For crash severity, the highest level was also found for the quartile of suburbs with the highest population density (quartile 4). This finding is also to be expected, given the greater levels of public transportation serving high density urban areas.

5.4.2 Crash characteristics and RTIs

In terms of population-based rates and originating from the quartile analyses, many of the characteristics of the crashes showing higher percentages in the relatively lower population density suburbs (Quartiles 1-3), such as those involving single vehicles that overturned, animals and fixed objects, and occurring on wet roads, may be suggestive of the involvement of inappropriate or excessive driving speeds, as evidenced in other related international research (Brodsky & Hakkert, 1988; Chen et al., 2009; and as reviewed by Odero et al., 1997 and Peden et al., 2004). Excessive driving speed is also commonly cited as one of the reasons for relatively higher injury rates in low density rural settings, along with other high-risk driving behaviour such as drinking and driving and non-wearing of seatbelts (Besag & Newell, 1991; Dumbaugh & Rae, 2009; Strine et al., 2010).

Only the measure for the percentage of crashes involving articulated vehicles emerged from both the quartile and correlation analyses, and showed a positive association with the population-based rates, whereby higher injury rates in the relatively lower population density quartiles were associated with higher percentages of crashes involving articulated vehicles. Whilst the relatively higher involvement of large trucks in rural crashes has previously been described in other settings such as the United States (Muelleman & Mueller, 1996; Lyles et al., 1991), the data on crash characteristics in our study are restricted to prevalence rather than crash risk, the latter not being a focus of this study.

Based on both the quartile and correlation analyses, and as expected with the crash severity measure, high crash severity was shown to be associated with a relatively higher involvement of high passenger occupancy vehicles such as buses, minibuses and LDVs. In addition to having higher numbers of people exposed to crashes and injuries, public transport and in particular minibus taxis, also tend to be associated with overloading, unroadworthy vehicles and high levels of high-risk driving behaviour (Ribbens et al., 2008). Higher crash severities were also accompanied by higher percentages of cases occurring over weekends and at night. The relatively higher risk of crashes and injuries over weekends and during the night is well known, and is commonly associated with higher levels of high-risk behaviour, especially alcohol (Odero et al., 1997; Peden et al., 2004). With high crash severities involving high occupancy public transport vehicles, however, the weekend travel may also point to generally higher levels of mobility and travel exposure owing to increased exposure from recreational travel, as well as from the need to travel longer distances to services, or homesteads in the case of migrant workers.

5.4.3 Socio-economic deprivation and RTIs

In terms of population-based rates and based on the quartile analyses, higher fatality rates in the relatively lower population density quartiles showed to correspond with higher percentages for the education- and income-deprivation measures. The high rate of serious injury for pedestrians and high crash severity index in the highest density and typically urban quartile corresponded with the highest percentage for the measure of the percentage population living in a shack.

As with the crash severity measures, findings from the correlation analysis for the socio-economic deprivation measures did not correspond well with the patterns found with the quartile analyses. Based on the correlation analysis, only the percentage population living in shacks showed a statistically significant positive association with the population-based rates, which was for pedestrian-related fatal and serious injuries. The remaining education, employment and income deprivation measures were all positively associated with the measure of crash severity.

The association of higher crash and injury probability with lower socio-economic status is well documented (Borrell et al., 2005; Rivas-Ruiz et al., 2007; Spoerri et al., 2011). Further to the general social stresses from deprivation and inequality, and high-risk behaviour and practices by deprived populations (Babio & Daponte-Codina, 2006), area level deprivation, as evidenced from our measure of the percentage population living in a shack, is an important consideration in the context of road safety. In general, deprived populations tend to incur greater traffic-related risk exposure from greater mobility (Sonkin et al., 2006) or from needing to cross roads more often (Macpherson et al., 1998). However, consistent with our findings, pedestrians and especially children, have been shown to be particularly vulnerable to RTIs in high density urban settings (Spoerri et al., 2011; Petch & Henson, 2000). Inferior traffic infrastructure such as unsafe road crossings and transportation systems that do not accommodate the mobility of pedestrians, as well as road user and traffic conflicts arising from the diverse environments and land uses, may be important considerations to this observation.

5.5 Implications for prevention

The findings from this study have implications for addressing high-risk driving speeds, especially in low density settings, as well for strengthening relevant policies so as to secure targeted investments in priority areas, especially informal settlement areas. In light of competing pressures for municipal resources, there is merit in the use of resource-efficient strategies such as automated enforcement systems, including optimal speed camera technology (OECD, 2003), to deter high-risk driving behaviour, especially that related to speeding. High-risk driving behaviour, however, may also be symptomatic of large-scale spatial disparities resulting in long journeys with excessive times spent travelling, together with being exposed to unsafe transportation infrastructure. Hence, long-term planning strategies need to prioritise the reduction of travel-related exposure, especially to disadvantaged populations.

Following the general correspondence between deprivation and RTIs found in this study, as well as the strong predictive link shown between general deprivation and road traffic mortality (Sukhai & Jones, 2013), it will be important to address the range of “interlinked deprivations” (Vearey et al., 2010) arising from the complexity of the urban context, with priority afforded to the pockets of deprivation, including informal settlements, that are often concealed within large cities and suburbs. In addition, measures of social and area deprivation may also serve as important indicators of traffic-related risk within broad spatially targeted developmental policies, or within narrower policies focussed on traffic safety and transportation. Whilst some national attention is provided to small area deprivation through the “Presidential Poverty Nodes” (DPLG & Business Trust, 2007), it is important that systematic and relative small area prioritisation be used across the EMA.

The policy and practice implications from this study are especially timely given the recent announcement by the Minister of Finance in his annual budget speech, of a proposed “Cities Support Programme”, focussed on improved spatial planning, public transport systems, and management of infrastructure utilities (Gordhan, 2012). In addition, a “Municipal Infrastructure Support Agency” targeting rural municipalities that lack planning capacity is also proposed. The findings from this research may also be applicable to other metropolitan areas and large cities in the country, because socio-spatial disparities and other negative effects from historical policies in the country are not expected to be restricted to the current study setting.

With the backdrop of widespread failure of urban planning to address the needs of the majority of residents in urban areas, the UN-HABITAT Global Report on Human Settlements (UN-HABITAT, 2009) has stressed the importance that countries develop overall national urban strategies to deal with urbanisation as a positive phenomenon. Such strategies would be important to accommodate the dynamic nature of cities and their changing population densities as well as to provide opportunities for developing more coordinated and integrated policies and strategies across a range of disciplines and departments; including urban planning, transport, health, and social services. Spatial development frameworks provide the spatial component of integrated development plans for cities, but the focus has been criticised as being too broad and conceptual (Breetzke, 2009). The Global Report on Human Settlements has also emphasised the importance for such spatial frameworks to be more closely linked with infrastructure development and to have transport-land use links prioritised. In addition, innovative and more sustainable spatial forms such as “compact cities” and “new urbanism” that argues for medium- to high- built densities for cities, and at the level of the local neighbourhood, would be useful to consider for addressing some of the shortfalls of historical urban planning (UN-HABITAT, 2009).

Following the general benefits for urban densification (Turok, 2009), there may also be merits from a road safety perspective. Road safety may benefit through environments that discourage high speeds, reduced travel and exposure from improved connectivity, and the development of safe and viable transportation systems that are usually part of broader densification strategies. Following the severe socio-spatial disparities from the country’s legacy of apartheid and colonisation, as well as the limited progress made in redressing the harmful consequences arising from these policies and practices, urban densification may also provide opportunities for driving and sustaining remedial strategies. Opportunities for residential densification may be around the central city and in inner suburbs, and the corridors between the three broad clusters of very high population densities in the EMA, indicated earlier. Of note, however, is that road safety has thus far not been considered in local strategies on densification, nor does it feature with any prominence in international literature that examines urban densification. It is imperative, however, that densification strategies be aligned with broader spatial development strategies within the country that include priorities relating to health, safety and deprivation.

5.6 Strengths, limitations and future research

Our study has revealed important findings for understanding the geography of RTIs at the small area level in South Africa. In addition to spatial mapping and correlation analyses, we used exploratory quartile analyses (aggregated over a five-year period) that showed to be a simple yet useful technique for examining the correspondence between our outcome and explanatory measures. Further, in the absence of a theoretical underpinning to support a dose-response linear relationship between population density and RTIs, analyses using quartiles or other quantiles are recommended, so as to provide a more reliable assessment of RTI risk. Differing injury severities and road user groups were considered, as well as a measure of crash severity that has rarely been used in other research but has shown to be an important discriminator for the geographical disparities shown for this study setting. Findings from the negative binomial regression models also showed the significant predictor effects of population density on a range of RTI outcomes. The effects of population density however, could only partially be explained by the crash and socio-economic measures included in this study.

Our study however, suffers from three key limitations. First, typical of small area analyses, our findings are affected by the problem of small sample sizes. Whilst the use of quartile analyses would have helped minimise the small number problem, this bias should be kept in mind especially with the interpretation of findings on the population-based rates. Second, we were restricted by having data only at the group level, and in the absence of individual level data, we were not able to appraise differences in crash characteristics between the various road user groups. Third, as is often the case with data on crashes and RTIs, under-reporting is a serious challenge. In addition, there may also be an element of geographical bias in the analyses, because under-reporting tends to be a bigger problem in rural than in urban areas (Aptel et al., 1999), and may also be more particular in the case of non-fatal injuries that are more likely than fatal injuries not to be registered within the health care system.

Further small area analytical research will be useful to better understand the disparities shown in this study. Specifically, other GIS-based small area measures such as measures of accessibility or of relative deprivation would be useful in considering future work, especially for further explicating the influences of population density on crashes and RTIs. Whilst beyond the scope of this study, it would also be useful for future predictive-type modelling to build on findings from this research, by employing more advanced methodologies, including Bayesian approaches to account for small sample sizes (Jia et al., 2004; MacNab, 2004).

5.7 Conclusion

This research brings due attention to urban health and safety in the country, and has yielded novel insights on the nature, extent and distribution of injuries for the EMA. In addition, the presence of geographical disparities for disaggregated injury severity and road user groups, with relatively worse injury outcomes for low density areas, was confirmed at the small area level. The variations in RTIs, using a population density framework, showed to correspond with several measures relating to the characteristics of crashes, and measures of socio-economic deprivation. Whilst findings on the characteristics of crashes proxy many of the previously described risks, the findings on deprivation provide additional perspectives on rural-urban variations in RTIs, at least in a South African setting. It is imperative that spatial and developmental policies, especially at the city level, recognise these influences on road safety.

Chapter 6

General Discussion and Conclusions

6.1 Summary of principal findings

Within this thesis, a predominantly geographical approach was adopted, in order to understand the physical and social environmental influences on RTIs in S.A, using various spatial and spatial-temporal frameworks, and empirical models. The research has yielded several interesting findings and insights relating to the role of the physical and social environments on the occurrence of RTIs in the country. This final chapter reviews the evidence and understanding attained from the research advanced in the preceding chapters, where-after the overall benefits and pitfalls of this research, as well as opportunities for further research are discussed. A summary of the key findings arising from the analytical studies is presented in Table 6.1.

Chapter 2 focussed on understanding the epidemiology and risk of RTIs in S.A using various measures of rurality and exposure, and disaggregated by differing population and road user groups. The risk for RTFs showed substantial variations by population and road user characteristics, temporal and seasonal characteristics, and measures of rurality. Findings showed rurality to be an important area-based dimension to the geography of RTFs in S.A. The effect of rurality is, however, complex, and was shown to be dependent on the choice of exposure-based indicators, the choice of rurality measures, and the nature of data aggregation. In terms of exposure, the vehicle-based fatality rate showed to be better than the population-based fatality rate at discriminating rural-urban fatalities. In terms of rurality, the percentage rural population and the person-weighted population density measures were generally found to be better measures of rurality in the context of RTIs in S.A.

The findings provide initial insights into the descriptive and geographical epidemiology of RTFs in S.A that would be useful to guide policy and practice decisions for road safety, especially for risk-based priorities based on the epidemiology and risk of RTFs. Importantly, the research has also highlighted the importance of caution when using risk and rural-urban criteria to guide decision-making. Varying measures of rurality and risk, as well as patterns by disaggregated road user groups should be considered, owing to the disparate findings found in this study, and in order to avoid biased conclusions and inappropriate decision-making.

In Chapter 3, a province-week spatial-temporal framework was used to examine the factors associated with temporal variations in RTFs in S.A. Findings from the multivariable NARX model showed travel-related exposure and drink driving to be the key factors that explained the temporal variation in RTFs.

This research has demonstrated the use of an analytical framework, with data at a fine weekly temporal resolution, to yield important predictors of RTFs in the country. In addition to using a very fine temporal resolution and allowing for combined space-time variability, this approach allowed us to investigate effects such as different types of holiday that may be best captured using a space-time approach. Given the potentially modifiable nature of drink-driving, the findings have implications for deterring this high-risk driving behaviour, including enhanced enforcement strategies for the detection and prosecution of offenders. In addition, in the longer term, road safety policies should strongly accommodate the need to reduce dependency on motorised transport, especially private vehicle travel, through expansion and enhancements to public transportation systems where good practice mass transit systems should also be considered.

In chapter 4, a detailed geographical analysis was undertaken to examine the physical and social environmental factors associated with spatial variations in RTFs in S.A. Findings from the multilevel negative binomial regression models revealed a number of social and environmental variables associated with the geography of RTFs in S.A, including measures relating to violence and crime, driver behaviour, traffic exposure, socio-economic deprivation, and population density. The population density measure showed the strongest magnitude of effect on RTFs, which confirms some of the preliminary rural-urban associations found in chapter 2. The population density finding pointed to higher levels of

RTFs in rural areas, which is consistent with findings from many other country settings. Of particular relevance to the S.A setting, however, was the significant positive association found between RTFs and cases of violence and crime in South Africa, as evidenced by a general 'violence and crime index' measure, as well as a DUI measure.

This research provides new insights on the predictors of road traffic mortality in the country where a large range of possible social and environmental influences were accounted for. The effects of several socio-economic deprivation-related variables including education attainment, crime and violence, and rurality were found together to be significant predictors of the geographical variations of RTFs by police areas in S.A. These findings point to deprivation operating at a much broader complexity than with a single poverty-related measure, and have strong implications for the development of integrated resource-efficient strategies for addressing the underlying structural factors that underpin injuries and crimes in general, such as substance abuse and poverty, and for targeting antisocial behaviour in general, including that arising from adverse driving and violence and crime-related behaviour.

In Chapter 5, small area variations in RTIs at the suburban level for the EMA was examined, along with influences relating to the characteristics of the crashes and socio-economic deprivation, using population density as an organising framework. As found in the previous research at more coarse geographical scales in Chapters 2 and 4, a general inverse pattern between population density and RTIs was shown at a small area level, and for both fatal and serious injury rates. The relatively higher burden of rural crashes and injuries was shown to be associated with a relatively higher involvement of single vehicles that overturned, of animals and fixed objects, and of crashes occurring on wet roads, which may be suggestive of inappropriate or excessive driving speeds. The measure for the percentage population living in shacks showed the strongest association with the rates of RTIs and particularly for pedestrians, pointing to possible influences of area level deprivation. The remaining measures of socio-economic deprivation showed to be more strongly related to the crash severity index measure, which may relate to relatively higher vehicle occupancy and hence a higher number of people exposed to RTCIs. Findings from the negative binomial regression models showed population density to be a significant predictor of all RTI outcomes, but the effects of population density could only partially be explained by the crash and socio-economic measures included in the study.

The findings from this small area analysis have implications for addressing high-risk driving speeds, unsafe traffic and transportation infrastructure especially in pockets of informal shack developments that may exist within large cities and suburbs, and unsafe public transport. Many of these risks may relate to spatial disparities arising from historical planning policies, hence, it will be instructive to incorporate strategies with which to address these risks within broader policies that embrace more sustainable spatial forms such as “compact cities” and “new urbanism.”

Table 6.1: Summary of key findings from analytical studies

Description	Setting	Scale of analysis	Years	Effects considered*	Key findings
Geographical epidemiology and risk	South Africa (National)	District Council Municipality (n=53)	2002-2006	**Outcome measures:** • Counts and percentages • Population- based fatality rates • Vehicle- based fatality rates **Explanatory measures:** • Rural-urban characteristics (4) • Demography (3) • Temporal characteristics (3)	**Uni- and Bi-variate findings** • High rates among blacks, males, economically active age groups, and pedestrians • High driver rates among males and the white population group • Large proportion of cases over evenings and weekend hours • Non-linear relationship between rurality and traffic fatality risk • Vehicle based fatality rate a better discriminator than the population based fatality rate at differentiating rural-urban fatalities • Highly urban areas had the lowest fatality rates • Percentage rural population and person-weighted population density measures more reliable measures in SA setting
Integrated spatial-temporal analysis	South Africa (National)	Province-Week (n=2340)	2002-2006	**Outcome measure:** • Fatality counts (expected counts as offset variable) **Explanatory measures:** • Travel exposure (5) • Alcohol-relatedness • Weather and daylight (10) • Days of public holiday (3)	**Statistically significant predictors from multivariate analyses** <u>Positive associations between RTFs and</u>: • Travel exposure (through fuel sales as a proxy measure) • Alcohol relatedness • School holidays
Fine scale geographical analysis	South Africa (National)	Police areas (n=993)	2002-2006	**Outcome measure:** • Fatality counts (expected counts as offset variable) **Explanatory measures:** • Measures of violence, crime and traffic offences (4) • Indicators of traffic exposure (6) • Measures of travel-related risk (17)	**Statistically significant predictors from multivariate analyses** <u>Positive associations between RTFs and</u>: • Violence and crime rates • DUI • Travel-related exposure (from car travel) • Socio-economic deprivation (from education) • Wind speed

Table 6.1 continued

				• Socio-economic characteristics of resident population (12) • Area-based measures of rurality (7) • Land cover characteristics (8) • Road network characteristics (5) • Elevation (2) • Climate (11)	<u>Negative association between RTFs and</u>: Area-based population density
Small area analysis	eThekwini Metro / City of Durban	Suburbs (n=68)	2005-2009	**Outcome measures:** <u>Quartile analyses</u>: • Population-based fatal and serious injury rates disaggregated by road user groups • Crash severity index <u>Regression analyses</u>: • Fatality counts (with population size as offset variable) **Explanatory measures:** • Day of week (2) • Time of Day (4) • Road Condition • Crash type (5) • Vehicle type (6) • Socio-economic deprivation (4)	**Uni- and Bivariate findings** • General inverse relationship between RTIs and population density for fatal and non-fatal injuries (exceptions for serious injuries in the pedestrian injury group, and for the crash severity index) <u>Higher injury rates in low density rural areas associated with higher levels for proxy measures of</u>: • Inappropriate or excessive driving speeds • Excessive travel exposure • Social deprivation (from income and education measures) • Area level deprivation (from informal shack settlement measure) <u>High levels of crash severity associated with higher percentages of cases</u>: • Occurring over weekends • Involving public transport vehicles • Showing area level deprivation **Statistically significant predictors from multivariate analyses** <u>For all injury outcomes</u>: • Percentage of crashes involving fixed objects • Population density

*Number in brackets indicates the number of measures considered for the effect

6.2 Strengths and limitations

There are many strengths of the research covered in this thesis; however, there are also some inherent limitations that have implications for future research on understanding the occurrence of RTCIs, especially in the South African context. Many of these issues have already been discussed within the individual analytical chapters and hence are not repeated here. However, a general discussion is presented below on some of the key strengths, followed by some of the general and mostly cross-cutting limitations of note.

6.2.1 Strengths

In accordance with the adopting of a systems-oriented geographical approach, a very large range of effects was considered, some of which have not been investigated before, and data was aggregated at differing spatial and spatial-temporal scales in order to address some of the complexities and interacting influences on RTIs in S.A. In addition, the inclusive approaches used with variable selection were important in order to minimise spurious findings owing to the effects of omitted variables.

It was important to consider various geographical scales in this research, given that risk-generating mechanisms are expected to vary at different scales. Road traffic outcomes at one scale are also likely to be influenced by processes at other scales; hence the benefit of studying differing scales within the same framework, as with the multilevel analysis adopted in this research. Findings that are sensitive to scale are also important contributors to geography-specific policies and practices such as at the city, province or national tiers of government. Similarly, risk-generating processes may also vary with time, or in a combination of time and space, and hence the space-time framework used in this research contributed added opportunity for understanding the occurrence of RTIs in the country.

Overall, the frameworks allowed for modelling a larger amount of variability in the outcome measures than conventional analyses, that tend to be undertaken at coarser spatial and temporal scales, and using single level analyses. In contrast, a narrow and exclusive focus on fine-scale analyses (such as for small areas) in research and policy has also been questioned and described as the ‘Local Trap’ in the field of development planning (Purcell & Brown, 2005). Following the findings from this research, some effects were also shown to be particular to the framework adopted such as the effect of school holidays when using a space-time framework, and the effects of violence and crime, education deprivation, and population density when using a detailed geographical framework. In addition, the effects of area level deprivation and especially for pedestrian-related injury, were only captured using a fine-scale small area analysis, using the population living in informal shack dwellings as a proxy measure

6.2.2 Limitations

Following the geographical and spatial-temporal frameworks used in this research, group level analyses were appropriate in helping to understand many of the contextual effects that operate at an aggregated level, such as those arising from urbanisation or area level deprivation. However, despite their utility and strengths, such approaches also have inherent limitations arising from data aggregation that should be borne in mind when interpreting and applying the findings from this research. These limitations include the "ecological fallacy" (Robinson, 1950), mobility of populations, and assumptions around uniformity of risk, congruency of measures used in the analyses, and autocorrelation, and that are discussed below.

Findings from this research have shown geographical and temporal measures to be related to aggregate injury outcomes and hence this research does not provide an indication of whether the measures have a direct effect on injury risk at the individual level. This challenge of drawing inferences to individuals based on group level data is well known and commonly described as the "ecological fallacy" (Robinson, 1950). Such inferences are problematic due to the bias that arises from the nature of data aggregation, as well as to possible effects of confounding with aggregated data. Given that this research is not intended to provide nor is capable of providing evidence for such effects at the individual level, the problem of ecological fallacy is unlikely to arise. However, such population-based findings at the aggregate level do not mean interventions targeting individuals would not be appropriate. For example, our finding revealed that areas with high levels of education deprivation tend to have higher rates of RTIs, does not necessarily apply to the individual level. However, it does offer valuable clues about possible individual level effect. Importantly however, the findings are not just crude estimates of individual level effects but also evidence for structural compositional and contextual effects that may also be amenable to ecological group-level interventions such as the provision of better access to education. Some important population-based risks were also shown from the aggregated national sample, for example with concentrations of young males, where targeted population-based strategies would also be applicable.

In terms of mobility, the travel and residential population between the different geographical areas used in this research is not expected to be stable. Within the various geographical units of analysis considered for analyses, the risk and exposure-based measures calculated are based on characteristics of the resident population and not on the general road user population that includes non-residents that may be at risk due to use of the road network. As a result, traffic generating and predominantly urban areas are expected to 'import' many visitors and may thus show inflated rates due to relatively lower numbers of registered people and vehicles that are considered in the denominators of these measures. Likewise, areas having relatively more motorists undertaking the major part of their journeys outside their areas of residence will tend to show a reduced risk. This bias would more likely be reflected in the rates for highly mobile demographic populations. Similarly, group level data assumes that risk of RTIs is uniform within areas or temporal units, which is rarely expected to be the case. Some of the above effects have, however, been minimised in this research, by examining exposure-based indices at the relatively large province, district council and police area levels, and by undertaking analyses at differing spatial scales, including a small area analysis, in order to capture the underlying processes at different scales.

Following the aggregation of cases for the analyses, some of the explanatory data was not available for the precise period of the outcome data, hence, some assumptions and proxies needed to be established. For example, whilst much of the research was undertaken for the five-year period from 2002-2006, the last census data were only available for 2001, and therefore measures generated from the census data were used to proxy these effects for the time period of RTIs. In addition, in the absence of good quality data on some measures of interest, several related proxy measures were considered for analyses such as those relating to traffic exposure, travel-related risk and adverse driving behaviours (captured by measures of traffic offences). Depending on the quality and conceptualisation of the proxy measures, the actual effects of interest may be difficult to capture. For example, the vehicle population measure used as a proxy for traffic exposure does not provide any indication on the actual usage of the vehicles in the traffic environment, which would be a better measure for exposure. The measures relating to traffic offences including speeding, seat belt usage, and driving under the influence of alcohol (DUI) may also have been affected by detection bias, as infringements would more likely be detected in areas and times when enforcement operations are optimal. For example with DUI, enforcement strategies tend to be concentrated during the popular holiday seasons and in urban areas with major road networks and high traffic volumes. Accordingly, traffic infringements would more likely be captured during such periods and in areas where relatively higher levels of enforcement are carried out.

A further inherent limitation with grouping is autocorrelation, defined as the correlation between members of a series of observations, and that can occur with time series or spatial data (Majumdar et al., 2004). From a time series perspective, it is generally easier to accommodate autocorrelation within time series models, as with the spatial-temporal analysis undertaken, owing to the chronological order of successive observations (Majumdar et al., 2004). The negative binomial multilevel model used for the geographical analyses was, however, not capable of accounting for spatial autocorrelation. Whilst controlling for spatial autocorrelation has been shown to be less important than for temporal autocorrelation (Majumdar et al., 2004), and differences in the model coefficient estimates tend to be negligible, there is the possibility of exaggerated t statistics from the standard errors of the coefficients being underestimated (Rasbash et al., 2009). Consequently, for example, the marginally significant effect of wind speed in the detailed geographical analysis by police areas may not show to be significant in spatial models that adjust for spatial autocorrelation.

Finally, following the ecological nature and cross-sectional design of the studies undertaken, causality cannot be inferred from the results. These findings do, however, provide novel insights on the predictors of RTIs in the country, that are important for generating hypotheses for further analytical research targeted at further understanding, and establishing causal links between RTIs and some of the significant effects found in this study.

6.3 Implications for policy and conceptual understanding

The research undertaken in this thesis has shown the important influences of the social and physical environment on RTCIs in S.A, with most being development-related, and which is also likely to be the case for many LMICs. In addition to the measures relating to alcohol and travel exposure that are commonly found to be associated with RTCIs in many other high and low to middle income countries, this research has shown the important effects of measures relating to social and area deprivation, violence and crime, and rurality. Hence, for the S.A context and other LMICs, it is important that road safety policy and practices are closely aligned and as far as possible integrated with other developmental policies, especially those relating to public health, traffic and transportation, and social and economic development. Social development may incorporate initiatives that target poverty alleviation, skills development, as well as the context for high levels of substance abuse within the country. Such initiatives may be aligned with national strategies such as the Presidential Poverty Nodes" (DPLG & Business Trust, 2007) or with city-level strategies such as general integrated development plans, or newer targeted strategies such as the "Cities Support Programme" (Gordhan, 2012) that focuses on spatial planning, public transport systems, and management of infrastructure utilities.

Transport-related recommendations emerging from this research focus on the need for infrastructural upgrades in informal developments and other generally deprived areas, for reducing dependency on motorised transport, and for optimising enforcement strategies. Infrastructural upgrades should focus on contextually relevant engineering solutions for road crossing such as through the use of creative under- or over-passes in high risk environments and for separation of motorised and non-motorised transport. Improved and expanded public transportation systems such as rapid bus and rail transit systems show promise for reducing high levels of traffic exposure and for addressing related challenges around spatial disparities and accessibility to transport in the SA setting. The Transmilenio, a high-capacity BRT system in Bogotá, Colombia provides a good example of the success of such mass transit systems that has provided a range of transport as well as other developmental benefits to the City. In terms of the transportation sector, particular benefits centred on increased mobility with particular benefits to low-income households, and significant reductions in traffic injuries as well as levels of pollution. In addition, in the face of increasing levels of urbanisation, the Transmilenio was also shown to be instrumental in driving a process of densification (instead of sprawl) in selected areas over the past decade or so, which has been highly beneficial for urban development. Significant improvements were achieved with urban form, road infrastructure, public spaces, real estate investment, and land value in areas that it influenced (Bocarejo et al., 2013). Hence, mass transport systems may be an important consideration in the SA setting for the added benefit of providing a potential vehicle to drive future densification strategies, and to stimulate development and transformation of cities. In addition for the SA setting, a mass transport system may also serve an important vehicle to help regulate and integrate the current dominant minibus taxi industry within a new and formalised system for the country.

Following the identification of at-risk road user and demographic groups (such as males and young adults), periods (such as evenings and weekends), and areas (such as low density environments), targeted strategies focussed particularly on alcohol and speeding related infringements would be an important consideration. Enforcement strategies should also be expanded to increase the likelihood of detecting infringements such as through being more frequent and random, and optimised by incorporating automated resource-efficient technologies for the detection of high-risk driving behaviour. Given that high rates among young adults are generally attributed to the levels of brain development and emotional maturity, the implementation of a graduated driver licensing system may also be an important consideration. Such a system generally requires for novice drivers to demonstrate responsible driving behaviour under certain restricted conditions (such as not driving under the influence of any amount of alcohol or at night) before obtaining a final unrestricted licence. The proposed point demerit system for traffic offences through the Administrative Adjudication of Road Traffic Offences (AARTO) Act in the country is also expected to be important measure for regulating driver behaviour and its implementation should be expedited.

This research focuses on one dimension or component of the Haddon's Matrix (Haddon, 1970), being the environmental influences on the occurrence of RTCIs. The Haddon's Framework, however, does not capture the interacting influences of the various components of the traffic system together (road user, vehicle, and environment). The approach taken in this study is along the lines of a systems-oriented approach where the dynamic and interacting influences of the various components are considered. However, the Systems Approach, such as those adopted in Sweden and the Netherlands (Johansson, 2009; Wegman & Elsenaar, 1997) is largely intervention-focussed and does not provide for an analytical framework to capture this multitude of factors that contribute to the occurrence of RTCIs. In addition, the Systems Approach has not been applied to LMIC settings, and also does not prioritise or recognise the important influences of the environmental context of LMICs on RTCIs. Hence, whilst the principles of the Systems Approach may be important for any road safety assessment and strategy, their full implementation may not be the most appropriate and cost-effective strategy from a public health perspective for LMICs, especially owing to other competing development-related priorities. Following the findings from this research, a geographical approach may provide a useful analytical framework for understanding the social and environmental determinants of RTCIs, especially those from LMIC settings. Such an approach would also provide opportunities for understanding the broader determinants of RTCIs by integrating data from other components of the traffic system, including the driver and vehicle, and by using, for example, a multilevel methodology.

LMICs may also be better served by prioritising the basic and developmental influences on road safety, such as the development of optimal information systems, in order to help define priorities and driving under the influence of alcohol (DUI) in the short- to medium-term, and travel exposure and deprivation in the longer term. Systems-oriented ideas such as those adopted in Sweden and the Netherlands may be better suited to long-term strategies that could include a phased and systematic implementation. Relevant best practices from HICs, that are adaptable for LMIC settings, such as strategies for addressing DUI, could also be adopted in the short- to medium-term, though public health principles relating to cost-effectiveness and equity, and applications of these principles on priority populations such as vulnerable road users should also be considered.

As an example, the Colombian capital Bogotá halved their number of traffic-related deaths over an eight-year period from 1995 to 2002, using relatively basic road safety principles (Rodriguez et al., 2003; TransMilenio SA, 2001). This reduction has been attributed to a combined approach, comprising the following key measures: setting up of a unified injury surveillance system to help identify and prioritise safety actions; infrastructural upgrades to enhance the safety of pedestrians including the building of pedestrian bridges and pedestrian-friendly areas; development of a new mass transport system known as the TransMilenio; improvements to enforcement strategies and the performance of traffic police; and educational strategies to encourage safe driving behaviour, such as through the use of mime actors to point out to drivers when they are engaging in high-risk behaviour such as not wearing seat-belts, or failing to give way at pedestrian crossings (Rodriguez et al., 2003; TransMilenio SA, 2001).

There also remains significant opportunity for greater integration and alignment with national road safety strategies and policies in the country. For example, detailed strategic plans along with key actions are set out within a National Traffic Enforcement Strategy (2013-2020) as well as a transport engineering strategy through the SA International Road Assessment Programme (iRAP) (2011-2020), yet neither considers the broad context for the occurrence of road traffic injuries, nor are they located within a comprehensive road safety strategy within the country. Current initiatives are however in place to formalise a national road safety strategy that is aligned to the Decade of Action and that also includes a relatively systematic approach with adopting the 5 pillars of the Decade of Action as an organising structure. Although some recognition of safe systems is provided, a remaining challenge lies with incorporating a broader overlapping perspective to risk whereby the different components of the traffic system (as represented by the 5 Decade of Action Pillars) are seen as dynamic and interacting components. A further challenge lies with incorporating a social justice approach to the occurrence of road traffic crashes and injuries such that intervention strategies focus not only on proximal and predominantly behaviour-related risk factors such as excessive driving speeds, but are cognisant of the distal systemic risk factors such as deprivation that maintain inequities and social gradients in risk.

The research in this thesis has contributed to evidence on risks, critiques and debates towards the development of a revised National Road Safety Strategy (in the capacity of being a member of the reference group), and also towards the drafting of an "Integrated Strategic Framework for the Prevention of Injury and Violence in South Africa, 2012–2016" (as a member of the project team). The latter strategy is under review by the Department of Health whilst the revised National Road Safety Strategy is in the process of refinement. It is clearly apparent that ongoing consultation and dialogue is still required and would be vital for optimal road safety policies and strategies, as well as for aligning road safety policies and strategies with others that focus on social development in general.

6.4 Future research

Alternate analytical approaches such as intervention studies would be useful to confirm and provide stronger evidence for some of the findings emerging from this research. Future research would also benefit from exploring alternate model specifications, especially non-linear models and spatial models to adjust for spatial autocorrelation.

Owing to many variables that influence crashes being nonlinear, an artificial neural networks approach for example, has been proposed as an alternative to regression methods due to its relevance to multivariate non-linear problems (Abdelwahab & Abdel-Aty, 2001). These approaches also have the advantage of not needing to assume an underlying data distribution; also transformations of the variables are automated in the computational process (Abdelwahab & Abdel-Aty, 2001).

In dealing with spatial autocorrelation, Aguero-Valverde & Jovanis (2006) for example, used full Bayes (FB) hierarchical models with spatial and temporal effects, and space-time interactions to model fatal crash data for counties in Pennsylvania, the findings were then compared with traditional negative binomial (NB) estimates. The measures considered for analyses related to socio-demographics, weather conditions, transport infrastructure, and amount of travel. The estimates from the two approaches were generally consistent in direction and magnitude however, variables that were marginally significant in the NB models were generally not found significant in the FB models. This was particularly the case for precipitation that was significant and positive in the NB models, but not significant with FB models. Spatial autocorrelation was however only found to be significant for injury and not fatal crashes and the finding was attributed to spatial correlation being more influential at smaller spatial scales. As discussed earlier, adjusting for spatial autocorrelation may also render some of the marginally significant effects from the detailed geographical analysis non-significant. In addition to the use of spatial models as above, spatial autocorrelation may also be accommodated by considering other influences that operate at more coarse geographical scales than that undertaken in the current fine scale geographical analyses such as the effects from province-level road safety policies and interventions.

Whilst a large range of variables were included to understand the determinants of RTIs in South Africa, additional measures that have been shown to be influential on RTFs, and that may be worthwhile to consider in future research include: the design and layout of roads (Simcic & Townsend, 2008) that could potentially support excessive or inappropriate driving speeds such as elevation and curvature by different categories of road, access to advanced pre-hospital and hospital and trauma care, by incorporating distance and time measures for hospital facilities (Van Beeck et al., 1991; Baker et al., 1987) that may mediate the elevated risk in rural areas, socio-cultural factors that may manifest in different risk-taking levels through qualitative data (Rivas-Ruiz, 2007; Factor et al., 2008), and measures of relative deprivation (Noland & Quddus, 2004; Graham & Stephens, 2008) that have also been shown to improve model specifications, when included together with other deprivation measures, such as income (Salti, 2010). In the case of relative deprivation, indices of multiple deprivation have only been calculated for the provinces of South Africa at this stage. The measure provides the relative levels of deprivation within the provinces and is not comparable across provinces.

Finally, it would also be useful to further disentangle and explore the mechanisms involved in some of the relationships found in this research, especially the positive association found for the effects of deprivation and rurality on RTFs. In this regard, it may be beneficial to consider different conceptualisations of key influences on RTIs, based on the idea of relational views of space and place, whereby places are viewed as nodes within networks, compared with being discrete spatial units (Cummins et al., 2007; Graham & Healy, 1999). In addition to spatial measures, such relational perspectives may be obtained by incorporating differing conceptualisations of effects using various data sources and methods, and including data on residents' perceptions, observational data, and other qualitative assessments (Cummins et al., 2007).

6.5 Closing remarks

The research in this thesis contributes new insights into the occurrence of RTIs in South Africa with regard to their social and environmental influences. In addition, findings indicate that a large proportion of the systematic variations in RTIs may be explained by factors across spatial and temporal frameworks. Many of the influences were development-related, and integrated strategies across disciplinary and governmental department contexts are advocated. Urgent action is imperative, considering the country's target of a 50% reduction in RTIs by 2014, set in 2006 as part of the Millennium Development Goals for the transport sector.

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Appendix 1: Accident Report (AR) Form (Page 1)

Police station area where accident occurred
(* COMPLETE IF APPLICABLE)

AR no.

Form of

CAS / /

Accident Report (AR) Form

Serial number

Capturing number

Accident date (DD/MM/YYYY): / /

Day of week: Su M Tu W Th F Sa

Number of vehicles involved

Time of accident (24h) :

LOCATION Built-up area: 1. Yes 2. No Speed limit on road: km/h

Province 1. EC 2. FS 3. GP 4. KZN 5. MP 6. NW 7. NC 8. LM 9. WC

Street/road name/road number

TOWN / CITY

*At intersection with (Street/road name/road no.)

*Or between (street/road name/road no.)

and (street/road name/road no.)

*Suburb (if in city/town)

*City/town name

FREEWAY/ RURAL

*At intersection with (Road number/ name)

*Or approximately km measured in compass direction N S E W

from

(Describe fixed point e.g. town, river, bridge, culvert, intersecting street or road, on/off ramp of interchange, name of building/house, pole number, etc.)

*Information on kilometre marker: road no./section km ,

*Between (city/town) and (next city/town)

ROAD TYPE:

1. Freeway
2. On/off ramp
3. Dual carriageway
4. Single carriageway (two way)
5. One way
8. Other (specify)
9. On-road parking/rank
10. Off-road parking/rank

JUNCTION TYPE:

1. Cross roads
2. T-junction
3. Staggered junction
4. Y-junction
5. Circle
6. Level Crossing
7. Not a junction or crossing
9. On ramp/ slipway
10. Off ramp/ slipway
11. Pedestrian Crossing
12. Property driveway/ access
8. Other (Specify)

*GPS reading: X co-ordinate Y co-ordinate

PARTICULARS OF DRIVER A OR	DRIVERS/CYCLISTS	PARTICULARS OF DRIVER B OR
/ /	ID type/ ID number/ age	/ /
	Country of origin of ID	
	Surname	
/	Full name/ initials other names	/
	Residential/home address	
( ) H W	Telephone number	( ) H W
	Work/contact address	
( ) H W	Cellphone/other number	( ) H W
1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown	How would you describe the driver?	1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown
1. Male 2. Female 0. Unknown	Gender	1. Male 2. Female 0. Unknown
1. DL 2. LL 9. None / /	Driving/Learner Licence number & date of issue (DD/MM/YYYY)	1. DL 2. LL 9. None / /
A1 A B C1 C EB EC1 EC Other (specify)	Driving/Learner Licence code	A1 A B C1 C EB EC1 EC Other (specify)
1. Killed 2. Serious 3. Slight 4. No injury	Severity of injury	1. Killed 2. Serious 3. Slight 4. No injury
	Ambulance service, driver, case reference number & hospital	
1. Yes 2. No 0. Unknown	Seatbelt fitted/helmet present	1. Yes 2. No 0. Unknown
1. Yes 2. No 0. Unknown	Seatbelt/helmet **definitely** used	1. Yes 2. No 0. Unknown
1. Yes 2. No	Liquor/drug use **suspected**	1. Yes 2. No
1. Yes 2. No	Liquor/drug use: **evidentiary tested**	1. Yes 2. No
No Yes (Write particulars on page 3)	Any passengers/pedestrians?	No Yes (Write particulars on page 3)

DETAILS OF VEHICLE A OR	VEHICLES	DETAILS OF VEHICLE B OR
N S E W	Travel towards direction	N S E W
Check if front and back number-plate correspond with licence disc and expiry date of disc	Number plate number	Check if front and back number-plate correspond with licence disc and expiry date of disc
	Licence disc number	
	Colour	
	Make	
	Model (e.g. 280SE, ASTRA)	
&	*Trailer number plate number	&
1. Yes 2. No 0. Unknown	Carried passengers for reward? (e.g. bus or taxi)	1. Yes 2. No 0. Unknown
	Breakdown company, telephone number & driver name	

PAGE 1

Appendix 1: Accident Report (AR) Form (Continued, Page 2)

VEHICLE TYPE

Passenger vehicles: Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

01. Motor car or station wagon
02. Combi/minibus
03. Midibus
04. Bus
05. Bus-train

Goods vehicles: Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

06. Light delivery vehicle
07. Panel van
08. GVM>3500kg (greater than)
09. Truck: articulated
10. Truck: articulated multiple

Motor cycles: Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

11. 125cc and under
12. Above 125cc
13. Tri-cycle
14. Quadru-cycle

Other vehicles: Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

15. Bicycle
16. Mobile equipment: (driven)
17. Caravan/trailer
18. Tractor
19. Animal-drawn vehicle
98. Other (specify) ______

LIGHT CONDITION: (Mark ONE only)

1. Daylight 3. Night: unlit 8. Other (specify)
2. Night: lit by street lights 4. Dawn/dusk

WEATHER CONDITIONS AND VISIBILITY: (May mark more than one)

1. Clear 4. Mist/fog 7. Fire/smoke
2. Overcast 5. Hail/Snow 9. Severe wind
3. Rain 6. Dust 0. Unknown

ROAD SURFACE TYPE: (Mark ONE only)

1. Concrete 3. Gravel 8. Other (specify)
2. Tarmac 4. Dirt

QUALITY OF ROAD SURFACE: (Mark ONE only)

1. Good 4. Cracks
2. Bumpy 5. Corrugated
3. Pothole 8. Other (specify) ______

ROAD SURFACE: (Mark ONE only)

1. Dry 5. Snow 9. Water: standing or moving
2. Wet 6. Loose gravel or sand
3. Wet in areas 7. Slippery
4. Ice 8. Other (specify) ______

ROAD MARKING VISIBILITY: (Mark ONE only)

0. Unknown 2. Not good (specify) ______
1. Good 7. N/A

OBSTRUCTIONS:

1. Accident site 3. Roadblock 9. None
2. Roadworks 8. Other (specify) ______

OVERTAKING CONTROL: (Mark ONE only)

1. Barrier line 2. Road sign 7. N/A
9. None

TRAFFIC CONTROL TYPE: (Mark ONE only)

1. Robot
2. Stop sign
3. Yield sign
4. Officer
5. Officer+robot
6. Uncontrolled junction
7. Not at junction, crossing or barrier line
8. All robots out of order
9. Some robots out of order (specify) ______
10. Flashing robots (red/ yellow)
11. Boom
12. Pedestrian crossing
13. Barrier line

ROAD SIGNS CLEARLY VISIBLE:

1. Yes 2. No 7. N/A

CONDITION OF ROAD SIGNS:

1. Good 2. Not good 3. Damaged or missing
7. N/A (specify) ______

DIRECTION OF ROAD: (Mark ONE only)

1. Straight 2. Curving 3. Sharp curve 90 degree bend

FLAT OR SLOPED: (Write vehicle reference letter (A, B, C, etc.) in the blocks.)

A B 1. Flat A B 2. Uphill A B 4. Steep uphill
3. Downhill 5. Steep downhill

POSITION OF VEHICLE BEFORE ACCIDENT:

Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

1. Correct road lane
2. Wrong road lane (but right side of road)
3. Wrong side of road
4. Road shoulder
5. On-road parking bay
6. Off-road parking bay

VEHICLE MANOEUVRE/ WHAT DRIVER WAS DOING:

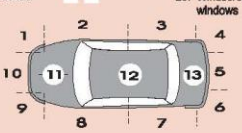
Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

01. Turning right
02. Turning left
03. U-turn
04. Enter traffic flow
05. Merging
06. Diverging
07. Overtaking: pass to right
08. Overtaking: pass to left
09. Travelling straight
10. Reversing
11. Sudden start
12. Sudden stop
13. Busy parking
15. Changing lane
16. Swerving
17. Slowing down
18. Avoiding object
19. Stationary (e.g. waiting in traffic)
20. Parked (e.g. in parking bay)
98. Other ______

VEHICLE DAMAGE: (More than ONE of the options below may be selected for each vehicle, if applicable.)

Write the vehicle reference letter (A, B, C, etc.) in the blocks. A B

01. Right front
02. Right mid-front
03. Right mid-back
04. Back right
05. Back centre
06. Back left
07. Left mid-back
08. Left mid-front
09. Left front
10. Front centre
11. Bonnet
12. Roof
13. Boot
14. **Multiple**
15. Caught fire
16. **Rolled**
17. Damage undercarriage
18. Damage no detail
19. No damage
20. Windscreen/ windows



ACCIDENT TYPE:

1. Head/rear end
2. Head on
3. Sideswipe: opposite directions
4. Sideswipe: same direction
8. Approach at angle - both travelling straight
16. Single vehicle: left the road
11. Single vehicle: overturned
12. Accident with pedestrian
13. Accident with animal (specify) ______
14. Accident with train
15. Accident with fixed/ other object (specify) ______

Was this a Hit & Run accident? 1. Yes 2 No

ACCIDENT SKETCH:

Show Direction North with arrow. Show direction, position and reference number of each vehicle, pedestrian, alleged point of impact, tyre marks, fixed point(s), and other object(s) involved. Measurements are optional.

BRIEF DESCRIPTION OF THE ACCIDENT:

PAGE 2

Appendix 1: Accident Report (AR) Form (Continued, Page 3)

SUMMARY OF PERSONS INVOLVED (including driver/cyclist)

1. Number of persons dead (killed):
2. Number of persons seriously injured:
3. Number of persons slightly injured:
4. Number of persons not injured:

PARTICULARS OF PASSENGERS WHO ARE NOT INJURED

Surname and initials | Passenger number | in vehicle (A, B, etc)
ID number / | Telephone/Cellphone number ( ) | H | W

Surname and initials | Passenger number | in vehicle (A, B, etc)
ID number / | Telephone/Cellphone number ( ) | H | W

Surname and initials | Passenger number | in vehicle (A, B, etc)
ID number / | Telephone/Cellphone number ( ) | H | W

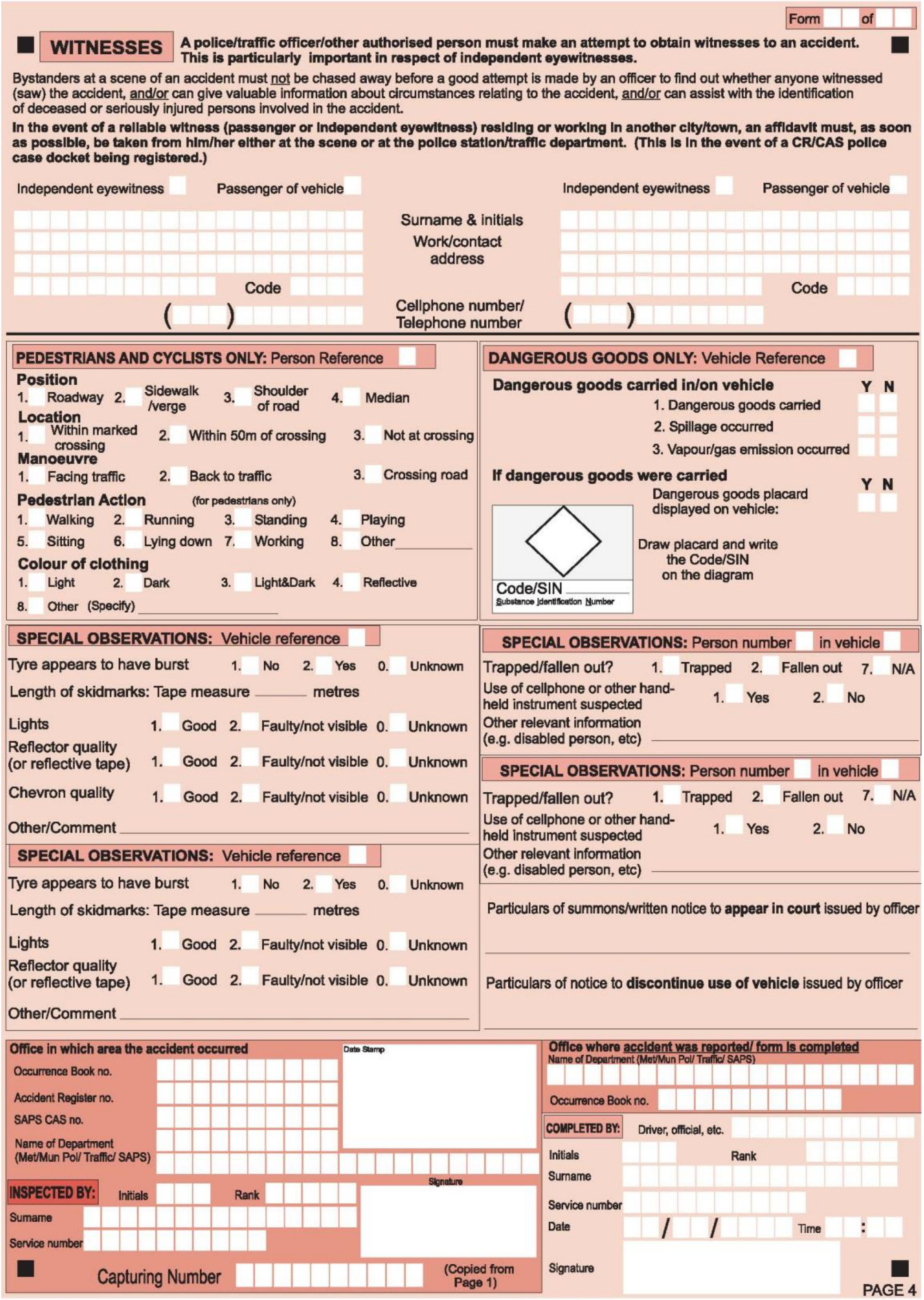
PARTICULARS OF KILLED OR INJURED PASSENGERS AND PEDESTRIANS

Passenger number (1, 2, etc.) in vehicle (A, B, etc.) / Pedestrian (P, Q, etc.)		Passenger number (1, 2, etc.) in vehicle (A, B, etc.) / Pedestrian (P, Q, etc.)
/	ID type/ ID number	/
	Country of origin of ID	
	Surname	
Initials / Age		Initials / Age
	Home/contact address	
( ) H W	Telephone number	( ) H W
( ) H W	Cellphone/other number	( ) H W
1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown	How would you describe the person?	1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown
1. Male 2. Female 0. Unknown	Gender	1. Male 2. Female 0. Unknown
1. Killed 2. Serious 3. Slight 4. No injury	Severity of injury	1. Killed 2. Serious 3. Slight 4. No injury
	Ambulance service, driver, case reference number & hospital	
1. Yes 2. No 0. Unknown	Seatbelt fitted/helmet present	1. Yes 2. No 0. Unknown
1. Yes 2. No 0. Unknown	Seatbelt/helmet **definitely** used	1. Yes 2. No 0. Unknown
1. Yes 2. No	Liquor/drug use **suspected**	1. Yes 2. No
1. Yes 2. No	*Liquor/drug use: **evidentiary tested**	1. Yes 2. No

Passenger number (1, 2, etc.) in vehicle (A, B, etc.) / Pedestrian (P, Q, etc.)		Passenger number (1, 2, etc.) in vehicle (A, B, etc.) / Pedestrian (P, Q, etc.)
/	ID type/ ID number	/
	Country of origin of ID	
	Surname	
Initials / Age		Initials / Age
	Home/contact address	
( ) H W	Telephone/contact number	( ) H W
( ) H W	Cellphone/other number	( ) H W
1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown	How would you describe the person?	1. Asian 2. Black 3. Coloured 4. White 98. Other 00. Unknown
1. Male 2. Female 0. Unknown	Gender	1. Male 2. Female 0. Unknown
1. Killed 2. Serious 3. Slight 4. No injury	Severity of injury	1. Killed 2. Serious 3. Slight 4. No injury
	Ambulance service, driver, case reference number & hospital	
1. Yes 2. No 0. Unknown	Seatbelt fitted/helmet present	1. Yes 2. No 0. Unknown
1. Yes 2. No 0. Unknown	Seatbelt/helmet **definitely** used	1. Yes 2. No 0. Unknown
1. Yes 2. No	Liquor/drug use **suspected**	1. Yes 2. No
1. Yes 2. No	*Liquor/drug use: **evidentiary tested**	1. Yes 2. No

PAGE 3

Appendix 1: Accident Report (AR) Form (Continued, Page 4)



Form of

WITNESSES

A police/traffic officer/other authorised person must make an attempt to obtain witnesses to an accident. This is particularly important in respect of independent eyewitnesses.

Bystanders at a scene of an accident must not be chased away before a good attempt is made by an officer to find out whether anyone witnessed (saw) the accident, and/or can give valuable information about circumstances relating to the accident, and/or can assist with the identification of deceased or seriously injured persons involved in the accident.

In the event of a reliable witness (passenger or independent eyewitness) residing or working in another city/town, an affidavit must, as soon as possible, be taken from him/her either at the scene or at the police station/traffic department. (This is in the event of a CR/CAS police case docket being registered.)

Independent eyewitness Passenger of vehicle | Independent eyewitness Passenger of vehicle

Surname & initials

Work/contact address

Code | Code

Cellphone number/ Telephone number ( ) | ( )

PEDESTRIANS AND CYCLISTS ONLY: Person Reference

Position
1. Roadway 2. Sidewalk /verge 3. Shoulder of road 4. Median

Location
1. Within marked crossing 2. Within 50m of crossing 3. Not at crossing

Manoeuvre
1. Facing traffic 2. Back to traffic 3. Crossing road

Pedestrian Action (for pedestrians only)
1. Walking 2. Running 3. Standing 4. Playing
5. Sitting 6. Lying down 7. Working 8. Other

Colour of clothing
1. Light 2. Dark 3. Light&Dark 4. Reflective
8. Other (Specify)

DANGEROUS GOODS ONLY: Vehicle Reference

Dangerous goods carried in/on vehicle Y N
1. Dangerous goods carried
2. Spillage occurred
3. Vapour/gas emission occurred

If dangerous goods were carried Y N
Dangerous goods placard displayed on vehicle:

Draw placard and write the Code/SIN on the diagram

Code/SIN
Substance Identification Number

SPECIAL OBSERVATIONS: Vehicle reference

Tyre appears to have burst 1. No 2. Yes 0. Unknown
Length of skidmarks: Tape measure ______ metres
Lights 1. Good 2. Faulty/not visible 0. Unknown
Reflector quality (or reflective tape) 1. Good 2. Faulty/not visible 0. Unknown
Chevron quality 1. Good 2. Faulty/not visible 0. Unknown
Other/Comment

SPECIAL OBSERVATIONS: Vehicle reference

Tyre appears to have burst 1. No 2. Yes 0. Unknown
Length of skidmarks: Tape measure ______ metres
Lights 1. Good 2. Faulty/not visible 0. Unknown
Reflector quality (or reflective tape) 1. Good 2. Faulty/not visible 0. Unknown
Other/Comment

SPECIAL OBSERVATIONS: Person number in vehicle

Trapped/fallen out? 1. Trapped 2. Fallen out 7. N/A
Use of cellphone or other hand-held instrument suspected 1. Yes 2. No
Other relevant information (e.g. disabled person, etc)

SPECIAL OBSERVATIONS: Person number in vehicle

Trapped/fallen out? 1. Trapped 2. Fallen out 7. N/A
Use of cellphone or other hand-held instrument suspected 1. Yes 2. No
Other relevant information (e.g. disabled person, etc)

Particulars of summons/written notice to **appear in court** issued by officer

Particulars of notice to **discontinue use of vehicle** issued by officer

Office in which area the accident occurred
Occurrence Book no.
Accident Register no.
SAPS CAS no.
Name of Department (Met/Mun Pol/ Traffic/ SAPS)

Date Stamp

INSPECTED BY: Initials Rank Signature
Surname
Service number

Capturing Number (Copied from Page 1)

Office where accident was reported/ form is completed
Name of Department (Met/Mun Pol/ Traffic/ SAPS)
Occurrence Book no.

COMPLETED BY: Driver, official, etc.
Initials Rank
Surname
Service number
Date / / Time :
Signature

PAGE 4