A GIS BASED APPROACH TO IDENTIFY ROAD TRAFFIC FATAL ACCIDENT HOTSPOTS IN THE GREATER DURBAN CITY FROM 2011 - 2015

by

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Submitted in fulfilment of the academic requirements for the degree of

Master of Science

in the School of Agricultural, Earth and Environmental Sciences,

University of KwaZulu-Natal

Westville campus

December 2017

As the candidate's supervisor I have/have not approved this thesis/dissertation for submission.

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ABSTRACT

Road safety is a serious problem across the globe and its severity is more prominent in developing countries, especially in Africa. South Africa is no exception and road safety is one of the major challenges the greater Durban City in the KwaZulu-Natal Province will have to overcome in order to achieve its vision of being Africa's most livable city by 2020. The prime goal of road safety is to reduce the number and severity of traffic accidents by identifying, implementing and evaluating measures to improve road safety. Road safety improvements are supposed to be applied to accident hotspots where they have the most significant impact, thus, identification of hotspots is an essential step in safety management. This study employed GIS spatial statistics tools to examine and map the trends and spatiotemporal distribution of fatal accident hotspots in the greater Durban city from 2011 - 2015. A total of 546 fatal accidents occurred that led to 594 fatalities. It was observed that the highest number of fatal accidents occurred in 2011, a year which marks the beginning of the UN Decade of Action for Road Safety. However, there was a declining trend from 2011-2013, with 2013 recording the lowest fatal accidents. Since 2013, fatal accidents saw an increasing trend until 2015. The majority (52.4%) of fatal accidents occurred on weekends, while 39.2% were recorded in March, May, June and December. Furthermore, the time period between 18:00-23:59 recorded the highest number of fatal accidents (33%). Ninety two and a half percent (92.5%) of fatal accidents resulted from human error, 67.9% of these resulted from a vehicle-pedestrian collision due to pedestrians entering the roadway when unsafe to do so. Dual carriageways accounted for 30.4% of the total fatal accidents, followed by freeways (26.7%) and single carriageways (25.8%).

Spatial clustering of fatal accidents and spatial densities of fatal accident hotspots were evaluated using Global Moran's I and Anselin Local Moran's I spatial autocorrelation, Kernel Density Estimation (KDE) and Getis-Ord Gi* statistics respectively. Moran's I and Anselin Local Moran's I show that the occurrence of fatal accidents were random, with the exception of 2012 which had a 1% less likelihood that clustering occurred. Ranking of hotspots using KDE was done with the help of pixel values of the observed locations while ranking of hotspots using Getis-Ord Gi* was done with the help of z-scores associated with statistical significance. Results of hotspot analysis delineated 22 hotspot locations at 90% - 99% confidence levels. Based on the Getis-Ord Gi* hotspot results, the N2 freeway is of critical concern as it appears consistently throughout the five-year period under study and accounting for 49.2% (29) of the total recorded fatalities. Fatal accident hotspots in the study area follow a Northeasterly-Southwesterly trend as determined by the directional distribution (standard deviation ellipse) function in ArcMap. The results can be effectively utilised by various agencies for adopting better planning and management strategies to reduce and prevent road traffic fatal accidents in the greater Durban City.

PREFACE

The work described in this dissertation was carried out in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville Campus, from July 2015 to December 2017, under the supervision of Dr Njoya Silas Ngetar.

This study represents the original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

DECLARATION – PLAGIARISM

I, Rudolphine Nyoni, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

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ACKNOWLEDGEMENTS

First and foremost, I thank the Almighty God for giving me strength, knowledge, ability and opportunity to undertake this research study and complete it. Without His showers of blessings, this achievement would not have been possible.

The success of this study greatly depended on the availability of road traffic accidents data. I therefore, thank Logan Moodley, Sandra Graham and Ashok Nansook from the Durban City Engineers Unit who provided access to free road traffic accidents data records for this thesis.

I acknowledge my supervisor Dr Njoya Silas Ngetar for not only being my research supervisor, but also being very patient and understanding during every trying times of this work. I extend my deep and sincere gratitude for providing constructive suggestions, valuable comments and guidance for this thesis.

I express my appreciation to the University of KwaZulu-Natal postgraduate funding and the financial support from the National Research Foundation (NRF) which made it possible for me to continue with, and complete my studies. I wish to clarify that conclusions arrived at are those of the researcher and are not necessarily to be accredited to the NRF.

Last but not least, my parents, Beauty Ncube and my late father Rudolph Nyoni, to whom I dedicate my work. I am grateful for the prayers, unconditional love, continuous support, encouragement and for constantly reassuring me that this study will reach a stage of completion.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

The road traffic system is considered as one of the most complex and dangerous systems people have to deal with on a daily basis. This complexity is also evident in road traffic accidents (RTAs) analysis as they cross the boundaries of engineering, geography and human behaviour (Sabel *et al*. 2005). RTAs are increasingly becoming a threat to public health and national development in many developing countries as they contribute to poverty by causing deaths, injuries, disabilities, grief, loss of productivity and material damages. RTAs are increasing day by day mainly because the increase in vehicle ownership and those of other sectors such as real estates and industries, which are greater than the pace of development in transportation (Prasannakumar *et al*. 2011; Eshbaugh *et al*. 2012; Gopalakrishnan, 2012). As a result, a lag exists between private expenditure on vehicles and the public expenditure to accommodate increased motorisation. Due to this lag, countries typically experience the rampant increase in traffic injuries and fatalities. RTAs have proved to be a global public health concern necessitating their incorporation into road traffic development and planning (Eshbaugh *et al*. 2012).

Currently, RTAs are estimated to claim approximately 1.24 million people per year and injure an additional 20-50 million (Eshbaugh *et al*. 2012). Injury and deaths due to RTAs are a major public health problem in developing countries where more than 85% of all deaths and 90 percent of disability-adjusted life years were lost from road traffic injuries (Nantulya, 2011). Globally about 3 400 people die each day with 91% of these RTAs fatalities occurring in low and middle income countries. The African region remains the least motorised of the six world regions of the World Health Organisation (WHO), however, it suffers the highest rates of RTA fatalities, with Nigeria and South Africa having the highest fatality rates estimated at 33.7% and 31.95% deaths per 100 000 population per year respectively (WHO, 2013a).

Road safety is thus a public health issue because for every individual killed, injured or disabled by RTAs, survivors, their families and friends are likely to suffer adverse prolonged financial debts, social, physical and psychological effects. If current trends continue, road traffic injuries, which are ranked ninth in the ten leading causes of the global burden of diseases, are projected to be the third-leading contributor to the global burden of disease and injury by 2020 (Eshbaugh *et al*. 2012).

In response to the public threat posed by RTAs, the United Nations General Assembly proclaimed 2011-2020 the Decade of Action for Road Safety aimed at stabilising and reducing the global road carnage (WHO, 2013a). Countries have been recommended to setup and implement concrete national plans and strategies on engineering, enforcement and education which are likely to improve road safety. Also, emergency medical services have been suggested to be implemented in the concrete road safety plans so as to treat injured persons in an attempt to reduce fatalities. Such commitment to improving road safety is predicted to save approximately five million lives over the decade of action for Road Safety and reduce African poverty in six hundred and twenty-nine thousand people and an increase of Gross Domestic Product (GDP) by US$234 (Gopalakrishnan, 2012). The launching of the decade for commitment to road safety has brought forth the proliferation of national traffic safety institutions, regulations and strategies. This has led to the improvement in road safety while still increasing the number of vehicles on the road in Europe and North America (Eshbaugh *et al*. 2012). While success has been recorded in high income countries, the same cannot be said about low income countries with special emphasis on the African continent which is a signatory to various developmental programmes yet lack the physical and social infrastructure needed to lessen RTAs (Eshbaugh *et al*. 2012). However, the task of devising effective solutions warrants spatiotemporal analysis of RTAs which can be achieved through the application of geospatial technology such as Geographic Information Systems (GIS) (Levine *et al*. 1995). GIS is a technology for managing and processing locational and related information (Longley *et al*. 2005).

Using GIS as a platform to identify and analyse spatiotemporal distribution of RTAs is essential as it permits the efficient manipulation, analysis and visualisation of spatial data. Capabilities and functions of GIS such as database query and display, spatial and network analysis and the interoperability offer a more robust understanding with regards to indicators of casual effects thus aiding proper decision making by traffic agencies (Hasseea, 2003). The identification and analysis of high accident prone zones, herein referred to as hotspots, with the aid of GIS has been considered as one of the elementary steps to lessen road accident rates and is important for the appropriate allocation of resources for safety improvements (Anderson, 2009; Chen *et al*. 2011).

Along with already available measures to improve road safety such as proper highway design, application of appropriate traffic control devices and effective traffic police monitoring, geostatistical analysis in ArcMap is more likely to aid optimal reduction of road fatalities and injuries as it permits the analysis of spatiotemporal patterns in the zones of traffic accidents. Deepthi and Ganeshkumar (2010) assert that numerous procedures to identify RTA hotspots have been suggested. These include Kernel Density Estimation (KDE), empirical Bayesian method, accident frequency method, accident rate methods as well as quality control method. KDE is one of the most common methods for hotspot analysis used to prepare RTA crash maps. This method calculates the density of accidents in a given search bandwidth known as its neighbourhood. It then develops a continuous surface of density estimates of individual accidents within a search radius/ bandwidth thus providing aesthetically and statistically significant outcomes (Erdogan *et al*. 2008; Anderson, 2009; Blazquez and Celis, 2013). Statistical significance of RTA hotspots on highways can be determined by local measures such as Getis-OrdGi* statistics (Getis and Ord, 1992) and local Moran's I (Anselin, 1995). The purpose of this study is to identify, map and examine the patterns and trends of road traffic fatal accidents and fatal accident hotspots in the eThekwini Municipality using GIS spatial analysis during the period 2011 to 2015.

1.2 The Research Problem

The burden of road traffic injuries (RTI) is rising substantially, notably in low-middle income countries, where rates are twice those in high-income countries (WHO, 2013a). This is partially attributable to the rapid rate of motorisation in many developing countries that has occurred without a parallel investment in road safety strategies and land use planning (Bekibele *et al*. 2007). South Africa is no exception as it records RTAs on a daily basis. Ms Dipuo Peters, the Minister of Transport, on the National Road Safety Summit in November 2015 stated that:

"Many lives continue to be lost on our roads. Road traffic fatalities are amongst the main causes of death in South Africa today. This results in serious social and economic costs for the country. The economic ramifications include the increase in the social development and health budgets spent. Of extreme concern is that 80% of road crash fatalities are adults and males aged between 19 and 34 years old. (Department of Transport, 2015)

An annual report by the Road Traffic Management Corporation (RTMC, 2015) for the year 2014 to 2015 shows that 4 500 people died on South African roads, with Gauteng, the western Cape and KwaZulu-Natal recording the highest deaths. The report also indicates that 80% of deaths were among the economically active population. Another annual report from RTMC (2014) mentions that a total of 1184 people were killed in 987 road accidents countrywide from 1 December 2014 to 30 December 2014 and that the province of KwaZulu-Natal had the greatest recorded accidents (205), followed by Gauteng with 156 and Eastern Cape with 136. Durban is constantly undergoing changes in land use and land cover especially in the transitional zone. The vehicle density in Durban indicates an alarming increase in the past few years due to increased vehicle ownership (eThekwini Transport Authority, 2005). On the other hand, road conditions remain the same resulting in increased incidents of traffic accidents. Deaths, injuries, and property damages due to these accidents are not only a major cause of personal suffering and financial loss to the victims, their families and friends, but also to society at large. On average, two people are killed on Durban's roads in an average of 150 accidents each day and the estimated cost of these accidents is approximately R6-million a day derived from assigning a monetary value based on the degree of severity using variables such as medical costs, vehicle damage and property damage (WHO, 2013a). Such alarming statistics show that Durban's roads are now exceedingly dangerous and that accidents prove to be a socio-economic burden on communities therefore, how to improve traffic safety has become a major societal concern.

Norman *et al*. (2007) attributed the high burden of traffic injury mortality in South Africa to unsafe road environments, poor enforcement of existing traffic laws, road rage and aggressive driving as well as alcohol misuse. Institutional interventions through legislation and enforcement such as speed controls, vehicle safety inspections and driver testing systems such as a compulsory defensive driver's course for drivers of public service have been implemented

(Norman *et al*. 2007). In addition, the government organises road safety campaigns such as Arrive Alive, issues traffic levies and fines and arrests for reckless driving (Osidele 2016). However, road traffic injuries and fatalities continue unabated.

Therefore, there is a need for optimising RTA resources by identifying areas of priority in the greater Durban City, since the beginning of the decade of action for road safety. This is aimed at providing a better understanding of the patterns and trends of road traffic fatal accidents in the study area. It is also important to find out the contributing factors associated with road traffic fatal accidents in the hotspots. In South Africa, RTA data is collected through the accident report forms, which are completed by the police. Data on RTA is then forwarded to a variety of agencies which include the Road Transport Management Corporation (RTMC), Statistics South Africa (Stats SA) and the National Injury Mortality Surveillance System (NIMSS) for storage and analysis, Statistics South Africa (Lehohla, 2009). The traditional way of RTA analysis has involved a plethora of statistical models (Oulha *et al*. 2013). However, statistical approaches to RTA neglects the spatial dimension of risks and their distribution. Spatiotemporal mapping and analysis of RTA hotspots in GIS is considered one of the elementary steps to lessen road accident rates (Anderson, 2009). This will assist in identifying such accident hotspots and caution road users accordingly.

1.3 Research Aim, Objectives and Questions

1.3.1 Research Aim

The overall aim of this study was to identify and map the spatiotemporal patterns and trends of road traffic fatal accident hotspots in the greater Durban City using GIS from 2011 - 2015.

1.3.2 Objectives

The objectives of the study were geared towards achieving the main aim of the study. These objectives are:

- To identify, map and examine the spatial patterns and trends of road traffic fatalities and hotspots in the greater Durban City using GIS from 2011 - 2015

- To identify, map and examine the temporal patterns and trends of road traffic fatalities and hotspots in the greater Durban City from 2011 - 2015
- To determine the causative factors of road traffic accident fatalities in the greater Durban City
- To provide possible recommendations that can be implemented to improve road safety in the greater Durban City

1.3.3 Research Questions

In order to address the above objectives, the following research questions were identified:

- Where and how are road traffic fatal accidents and fatal accident hotspots spatially distributed in the greater Durban City?
- When and how are road traffic fatal accidents and fatal accident hotspots temporally distributed in the greater Durban City? This question seeks to explore the time in hours, days and months at which most road traffic fatal accidents occur.
- What factors contribute to the occurrence of road traffic fatal accidents and fatal accident hotspots in the greater Durban City?
- What alternative measures can be implemented to improve road safety; minimise the occurrence and costs of road accidents in the greater Durban City? Strategies to lessen the road carnage as implemented by other governments are reviewed and suggested.

1.4 Description of the Study Area

1.4.1 Location of the Study Area

Durban is located on the eastern coast of South Africa in the Province of KwaZulu-Natal (Figure 1.1). It is planned and managed by eThekwini Municipality, (Dray *et al*. 2006). The municipality encompasses an area of 2 300km² with boundaries that extend to Umkomaas in the South, Tongaat in the North and to Cato Ridge inland (Dray *et al*. 2006). The undulating nature of the landscape has influenced the development of an urban form which follows a “T” shape as it stretches up and down the coastal plain and inland along the major transport route to the economic hub of Johannesburg (Marx and Charlton, 2003). The Golden Mile, developed as a welcoming tourist destination in the 1970s, as well as Durban at large, provide ample tourist attractions, particularly for people on holiday from other provinces.

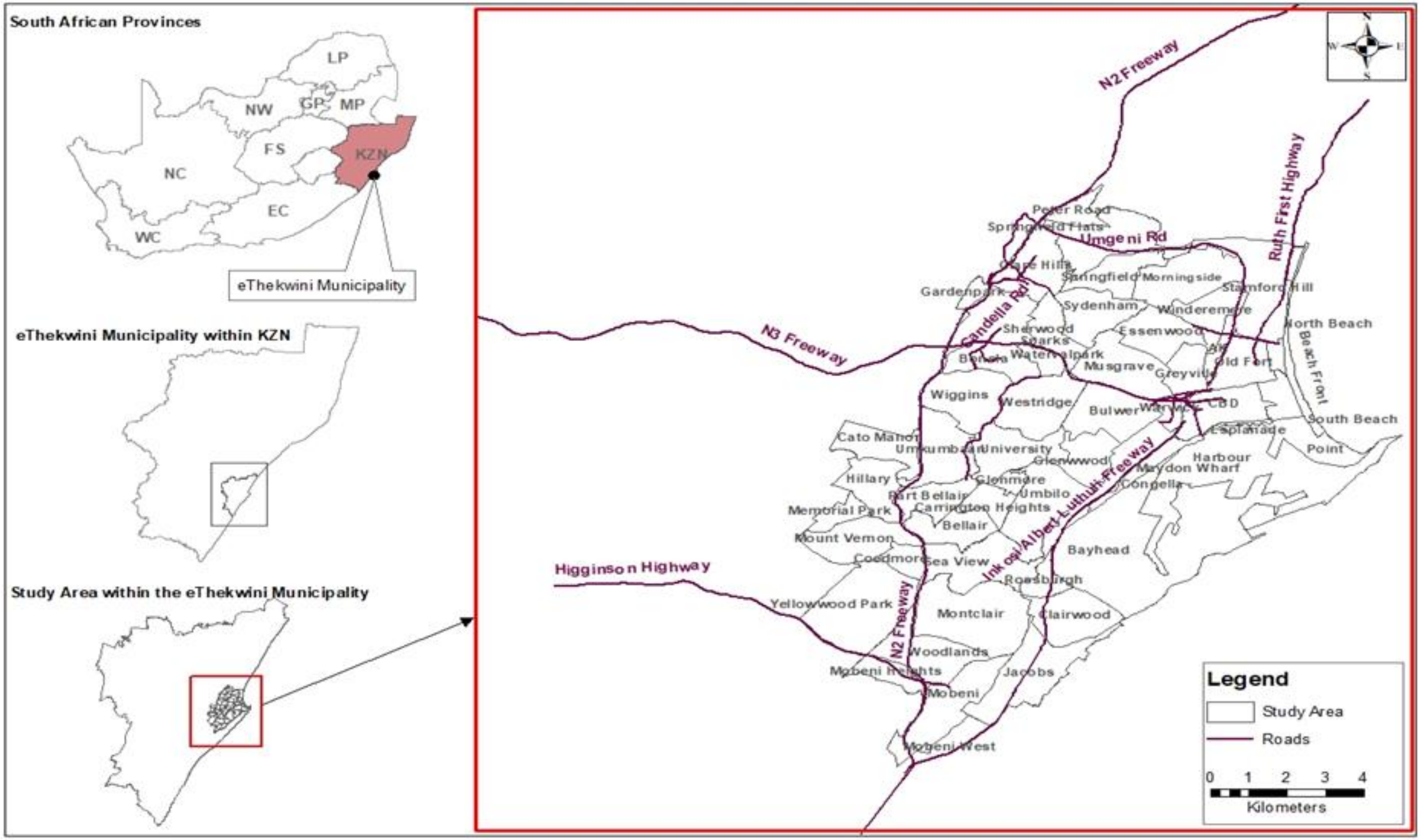

Figure 1.1 The study area in the eThekwini Municipality, South Africa (Data source: UKZN School of AEES).

1.4.2 Demographics

The eThekwini Municipality has a population of approximately 3.44 million people and it is the second most populated municipality in the country with a population of around 1 million households (Narsiah, 2010). Black South Africans constitute the majority of the Municipality's population (68%) whilst the Indian/Asian coloured and white populations constitute 20%, 3% and 9% of the total population, respectively (Dray *et al*. 2006). With regards to road traffic fatal accidents, it is worth noting that the impact of losing a family member is enormous both in terms of emotional trauma and /or loss of income, especially when the safety nets for victims of accidents is not strong enough to support the remaining family members (Olukoga, 2003).

1.4.3 Climate

Durban has a humid subtropical/ temperate climate (Marx and Charlton, 2003). The average temperature in summer ranges around 25°C, while in winter the average temperature is 18°C. Sunrise in Durban on summer solstice occurs at 04:45 and sunset at 19:00; on winter solstice, sunrise is at 06:30 and sunset at 17:20. The rainy season is in summer which begins in November, ending in mid-April. Summers are sunny, hot and humid during the day, but are relieved by afternoon or evening thunderstorms (Marx and Charlton, 2003). Durban is also occasionally affected by tropical storms and cyclones during the cyclone season, which is from 15 November to 30 April. Winters, which are from June - August, are generally warm and sunny. These weather conditions affect the occurrence of road traffic fatal accidents by enabling unsafe road environments such as driving under slippery conditions during wet condition and driving when sleepy or fatigued due to hot dry prevailing weather (Norman *et al.* 2007).

1.4.4 Economy

The eThekwini Municipal region is the third largest economic centre in South Africa. The growth of manufacturing industries centred at the port has been the most important aspect of the Durban economy since the 1920s and now accounts for about 30% of the local economy (Dray *et al*. 2006). Other sectors which contribute to the economy of Durban are tourism, finance and transport. These economic sectors and the growth of the economy foster the increase in vehicle density which perpetuates the likelihood of accidents as a result of vehicular-pedestrian mix on the roads (ETA, 2005). Moreover, the economic costs of accidents place a burden on the municipality budget, for an example, Olukoga (2003) writes that road traffic fatal accidents in 1998 costs the eThekwini Municipality US$151 million, which was equivalent to 13.1% of the 2003/2004 budget. Fatal accidents alone cost the municipality US$25.9 million.

1.4.5 Transportation and Road Networks

Durban's main position as a port of entry into South Africa has led to the development of national roads around it. The status of transport roads and rail infrastructure in Durban is primarily aligned to two main hallways, the coastal corridor which includes the national road (N2) and coastal rail lines, and the western corridor that links the Central Business District (CBD) with the inland areas and includes the national road (N3) (eThekwini Transport Authority, 2005). The N2 road links Durban with the Eastern Cape Province to the south and Mpumalanga Province to the north. The N3 western freeway links Durban with the economic hinterland of Gauteng. This road is predominantly important as freight is shipped by trucks to and from the Witwatersrand for transfer to the port. The N3 western freeway starts in the CBD and heads west under Tollgate Bridge and through the suburbs of Sherwood and Mayville. The EB Cloete Interchange, informally dubbed the Spaghetti Junction, lies to the east of Westville, allowing for transferal of traffic between the N2 road and the N3 road (eThekwini Transport Authority, 2005).

Population growth and employment opportunities have increased the absolute number of trips by both public transport and private (Lombard *et al*. 2007). Urban passenger transport in Durban is strongly reliant on public transport, with only 33% of the population having access to a car (NHTS, 2014). Public transport forms an integral part of economic growth, allowing locals and tourists access to more facilities and places of leisure, thereby expanding opportunities for trade. The main trip purpose split for South Africa using public transport is education (50%), work related trips (45%) and business trips (5%) (National Household Travel Survey, 2014).

A major component of the transport system of Durban is the daily commuter to and from the city, with the two main categories of public taxis as: minibus taxis (kombi) and metered taxis

(ETA, 2005). The intra-urban public transport structure comprises minibus taxi routes which reach to almost every part of the city which is accessible by taxi at a standard price of R5-R12 (Rand) depending on the area travelled. Low profit margins in some parts of Durban limit the ability of operators to recapitalise their fleets such that smaller taxis (cars) charging R50-R200 access these areas (ETA, 2005). Minibus taxis are independently operated vans that stop anywhere along their routes to drop off or pick up passengers, and they have by far the largest share of the public transport market due to their versatility and flexibility to offer point to point services, flexibility to market demand, flexibility to infrastructure capacity conditions in relation to traffic congestion and to changes in route and service frequencies (NHTS, 2014). With the high demand for transport by the working class and students, minibus taxis are preferred based on affordability and flexibility to deliver point to point services such that they are often filled beyond their legal passenger allowance (Arrive Alive, n.d). This translates to high injury and fatality rates when they are involved in traffic accidents as taxi drivers largely ignore the rules of the road (NHTS, 2014). Since minibus taxis are individually owned, although managed by a taxi association, inter-operator aggression and violence flares up from time to time especially as turf wars over lucrative taxi routes occur (Arrive Alive, n.d).

Another mode of the public transport system is metered taxis (cabs). These are taxis that provide a 24-hour service, although commonly used at night when other modes of transport are unavailable, to transport passengers within Durban (Pego, 2009). Unlike in other cities, metered taxis are not allowed to drive around the city to solicit fares, rather they are summoned by telephone and ordered to pick passengers at a specific location (Pego, 2009). Some common pickup and drop-off zones are the Gateway shopping centre, Pavilion shopping centre, Sun Coast Casino, King Shaka International Airport, Musgrave shopping centre, CBD and residential suburbs. Durban has various reputable metered taxi companies such as Mozzie, Eagle and Zippy (ETA, 2005). Method of payment is usually in the form of cash and prices can be negotiated upfront or the meter can be used to measure the distance travelled and charge according to the scale. UBER and taxify is another form of metered taxi which has become popular in Durban and across the country (Pego, 2009).

According to Gulston (2015), 25% of public transport users travelling by bus during the week leave as early as 5.a.m to arrive at their destinations on time, taking into account the intervals in bus schedules that cause a lengthy wait. Government influence is also prominent, particularly in relation to the regulated and subsidised bus mode through the contracting system and the unsubsidised minibus taxi mode that is regulated through the issuing of Operating Licenses (NHTS, 2014). The existing bus service comprises roughly 1 400 unidirectional routes provided by nearly 400 operators in a mix of subsidised contracts and unsubsidised services. Efforts to contain escalating subsidy along with reducing levels of service has been successful by the privatisation of the Durban Transport which accounts for more than one third of the bus fleet in the Municipality and operating on almost half of the bus routes (ETA, 2005). However, Durban Transport has over the years experienced many disruptions to service, making it unreliable for the majority of daily commuters who depend on this mode of transport (NHTS, 2014). Transport upgrades for the 2010 Fifa World Cup saw the improvement of road conditions, the railway service and pedestrian walk-ways, the bus service however, saw no major upgrades with the exception for the introduction of the People Mover in 2009 (Gulston, 2015). The People Mover provides service exclusively in the CBD and beachfront area.

Durban’s public transport system is largely inefficient and not satisfactorily customer focused with poor levels of reliability, predictability, comfort and safety (ETA, 2005). The NDP 2030 states that if the eThekwini Municipality is to fulfil its vision of elevating Durban’s status to becoming Africa’s most caring and liveable city by 2030, the implementation of the Bus Rapid Transit (BRT) system is necessary and such an undertaking is in the pipeline (Gulston, 2015). Durban’s BRT system is called the Go! Durban project, which is an eco-friendly development that will help to reduce the number of motor vehicles on the city’s roads by providing up to 85% of all residents in Durban access to safe, affordable and good quality, scheduled public transport (Gulston, 2015). This aspiration is hindered by the fragmented nature of institutional governance in passenger transport, resulting in complex regulations and by-laws and a subsequent lack of uniform safety and operational compliance standards (ETA, 2005; NHTS, 2014).

On the use of private transport, South Africa has seen exponential growth in car ownership over the past decades as the middle class grows against the backdrop of a public transportation system that has not improved satisfactorily to meet passenger expectations and is not adequately demand and developmental driven (ETA, 2005). Statistics by the Arrive Alive (n.d) show that there has been a 6.5% increase in the number of live vehicle populations between 2012 and 2015, which equates to an average of 8 758 live vehicle population increase per year. The percentage share of live vehicle population in Durban gives an idea of the volume of vehicles added to the streets every year, and these numbers include visiting and foreign registered vehicles commonly seen in Durban (ETA, 2005). In most cases, a vehicle is used by the driver alone or with other passengers who are dropped and collected at specific locations. During peak hours, private cars flood the roads such that one might conclude that more people rely on private transport than public transport (Pego, 2009).

Durban has become more pedestrian-friendly with wider, revamped pavements, adding to the aesthetic appeal (Gulston, 2015). Most pedestrians in the city are people walking from one mode of transport to another or those crossing roads to shops, schools or workplaces. Facilities aiding pedestrian movement in the city are traffic lights, zebra crossings, foot bridges, pedestrian walks and painted islands at intersections (Osidele, 2016). The safety of pedestrians is one of the major concerns for the transport and traffic authorities in South Africa. Vehicle drivers are regularly informed through the media such as radios and TV or intelligent based technology about the state of pedestrian concentrations along the roads especially during peak hours to enable them to lookout for pedestrians to avoid accidents (Arrive Alive, n. d).

Freight transport is the backbone of any country's economy. In South Africa road freight contributes 46% of the economy (Maoko, 2015). The road freight industry is rapidly developing, in both South Africa and Africa which offers numerous opportunities. Road is currently the primary mode of transport for freight for various reasons, with pipeline and rail having the backseat due to the sector being characterised by significant constraints. While road freight delivery has significant advantages, the number of freight vehicles on the road contributes to overloading and subsequent significant deterioration of the road network and traffic congestion (Maoko, 2015). This has resulted in the development and formulation of a Road-to-Rail Strategy by Transnet, of which the primary aim is to rebalance the road freight to rail freight split in an effort to create a more appropriate market share and a reduction of heavy trucks on the roads to relieve congestion on the road network (Transnet, 2012a). The implication is a reduction in overall transport and logistics costs and externality costs such as road damage, road congestion, road accidents, noise pollution and carbon emissions. The strategy is based on a qualified assessment of the state of South Africa's current rail infrastructure, costs of repair and maintenance, capital requirements and future market demand (Transnet, 2012b).

1.5 Significance of the Study

Accident information is useful to different stakeholders. The results of this study provides the Road Traffic Management Corporation (RTMC), eThekwini Municipality Transport Authority, eThekwini Municipality City Engineers, Police, Town Planners and drivers, with the spatial distribution of risky road segments and in particular, the location of road traffic fatal accidents hotspots in the greater Durban City. This information can be used as the basis for improving road safety by allocating resources in high priority areas (Anderson, 2009; Mitra, 2010; Chen *et al*. 2011). Thus it will provide the fundamental scientific approach in identifying, managing and preventing RTAs hotspots. The scientific approach is more likely to improve road safety and associated benefits, a commitment which over 100 countries have embarked on to set and implement ambitious national road safety plans in the battle to lessen the road carnage during the Decade of Action for Road. A safer road network is a sustainable one as transport is the heartbeat of South Africa's economic growth and social development. Moreover, it will add on to the literature on the application of GIS in identifying RTA hotspots.

1.6 Limitations to the Study

The research only focused on the patterns and trend analyses of road traffic fatal accidents in the greater Durban City after the UN commencement of action decade for road safety (2011-2020). The area managed by eThekwini municipality is large such that mapping RTAs in such a large spatial area would require a significant period, hence, the research focused on the greater Durban area. Due to large volumes of RTA data on all severities, this study focused only on fatal accidents, examining their patterns and trends. The RTAs data analysed in this study was obtained from the eThekwini Transport Authority and therefore subject to the completeness of their database. There were limitations in terms of the composition of age and gender to determine which of the age group is more involved in road traffic fatal accidents. Additionally, there were limitations in the composition of the type of vehicle involved in the fatal crashes to determine which vehicle class is more involved in road traffic fatal accidents. This hindered in-depth composition analysis in this study.

1.7 Conclusion

This chapter has outlined the challenge of RTA as a major global developmental and public health concern throughout the world. The South African context is discussed with a focus on the greater Durban City within the eThekwini Municipality. The aim, research objectives and research questions which act as a guide to complete the study. A description of the study area is presented, with more detail on the transportation and road networks, followed by the limitations and the chapter conclusion.

The next chapter is the theoretical review, which focusses on the burden, trends and factors that contribute to RTA with critical analysis of the contributing factors related to road users, vehicle factors and road-environmental factors. This chapter is followed by the methodology, a Chapter (Chapter Three) on GIS tools employed to determine RTA hotspots in the greater Durban City. Chapter Four presents the spatiotemporal pattern and trend analysis of fatal accidents, while Chapter Five maps and discusses hotspot areas of road traffic fatal accidents from 2011 – 2015. The last Chapter (Chapter Six) presents a summary of major findings and conclusions in this study, together with recommendations, which can be implemented to reduce the road carnage on South African roads.

CHAPTER TWO

THEORETICAL REVIEW

2.1 Introduction

Road Traffic Accidents (RTAs) are a result of complex processes. To enhance the level of road safety, it is essential to gain a clear insight into the underlying factors (Hermans *et al*. 2008). To shed light on this phenomenon, relevant literature focusing on road traffic accidents, including the theoretical frameworks explaining the probable reasons behind the occurrence of RTAs and the application of GIS to identify hotspot locations were reviewed. Holló *et al.* (2010) define a conceptual framework or model as an abstraction of reality, which helps to better understand the real world systems, facilitate communication and integrate knowledge across disciplines. To formulate appropriate road safety performance indicators a theoretical framework has to be developed. Specifically, a clear understanding and description of the problem under study need to be obtained. Research on RTAs has a long tradition in more economically developed countries such as those in the USA, Europe and Australia yet is still in its infancy in low and middle-income countries (Komba, 2006). Such a gap raises a debate on whether low and middle-income countries can adopt road safety strategies implemented in high-income countries, as they possess different cultural and developmental factors (Bishai *et al*. 2008). Regardless of these differences, Western frameworks on road safety can successfully be implemented by low and middle-income countries to improve road safety considering that road accidents are a result of interactive factors related to the road user, the vehicle and environmental factors irrespective of culture or level of development. The review focused on various books, peer reviewed journals, reports and editorials from government departments, agencies and non-government organisations. In addition, efforts were made to consider the views of different authors in relation to different themes on traffic safety from an international, regional and local perspective (Osidele, 2016).

2.2 Definition of Terms

Geographical Information Systems (GIS) - GIS is "a computer-based technology and methodology for collecting, managing, analysing, modelling, and processing, and representing geographic data for a wide range of applications" (Davis, 2001: 13). Thus GIS is a tool used to support decision making through the use of its functions and capabilities.

Hotspot - An accident hotspot is an engineering term to denote the section of a road network where traffic accidents frequently occur (Gundogdu, 2010). Hotspots in road traffic are also known as blackspots, dangerous spots or hazardous road sections, however, these accident prone areas have no universally accepted definitions as they are influenced by their identification procedures (Zovak *et al*. 2014). This explains why road safety councils and engineers, Police and researchers have used several different methods to identify accidents hotspots, which include and not limited to the number of accidents, accident density, accident rate, severity index, quality control methods and combined methods (Yang *et al*. 2013). Given such methodologies it is thus essential to define an accident hotspot as an area with not only a high accident frequency but also higher accidents rates than other similar locations where injuries, deaths or property losses occurred (Yang *et al*. 2013).

Patterns and Trends - As defined by Oxford university press (2001), a pattern is a particular way in which something is done, organised or happens, which could be on a regular repeated arrangement. On the other hand, a trend is a general development in a situation of occurrence. Road traffic injuries patterns and trends tend to look into the nature of occurrence of road crashes and possibly future projection (Oppong, 2012).

Road Traffic Accident (RTA) - is an unfortunate incident that happens unexpectedly and unintentionally (Oxford university press, 2001); between two or more vehicles, a vehicle and a train, a vehicle and a cyclist, a vehicle and a pedestrian, a vehicle and an animal, a vehicle and a fixed object such as a bridge, building, tree, post or a single vehicle that overturned on or near a public road (RTMC, 2015).

Road Traffic Injuries (RTI) - These are fatal or non-fatal injuries incurred because of a collision on a public road involving at least one moving vehicle (WHO, 2013a). Children, pedestrians, cyclists and the elderly are among the most vulnerable of road users.

2.3 Road Traffic Injury Theoretical Frameworks and Concepts

This study looked at theories related to road traffic accidents, with emphasis on the public health model, human-vehicle-environment interaction, exposure-risk-injury relationship, Haddon matrix systems approach, C3-R3 systems approach and GIS application on road traffic management. The choice of these frameworks is based on the notion that theories are fundamental tools in research problems, which facilitate the choice of methodological approaches to be used in studies as well as interpreting the findings (Elvik, 2002). Moreover, these approaches are relevant to the aims, objectives and problem statements of this study.

2.3.1 Public Health Model

According to the Association of Schools of Public Health in the United States, public health is defined as the science of protecting and improving the health of communities through education, policy making and research for disease and injury prevention (Association of Schools of Public Health, 2012). One of the fundamental principles of public health is the integration of multidisciplinary knowledge across the boundaries of biology, anthropology, public policy, mathematics, engineering, education, psychology, computer science, sociology, medicine, business, and others to formulate and implement strategies (Peden *et al*. 2014). As such, public health is largely useful in addressing large-scale population-based health priorities such as road traffic injuries (RTIs) (Bhuyan and Ahmed, 2013). The Centre for Disease Control and Prevention (CDCP, 2015) advocated the Public health approach as a scientific method for addressing injuries using public health principles. The approach consists of four core phases, defining and monitoring a problem; identifying the problem's risk and protective factors, developing and testing of prevention strategies and assuring extensive implementation of prevention strategies. The merits of this framework is that it has a feedback loop for continuous improvements.

A comprehensive study by Kress *et al.* (2012) indicated that the top violence and injury practice innovations that characterise public health principles and that contributed to the decline of injuries over the past two decades have been formulated. Among the strategies formulated, seven of these focused on road safety and included interventions targeting alcohol abuse and vehicle restraints. However, the public health model can be critiqued for prioritising interventions to RTIs, failing to offer a systematic and detailed framework for understanding the causative factors and their interactions in the road traffic safety system.

2.3.2 Human-Vehicle-Road Environment Interaction

The road transport system consists of three components: the road user, the vehicle and the road environment as represented in Figure 2.1. These components interact with other factors such that any malfunctioning of a component could ultimately lead to road safety problems (EU-OSHA, 2010). Studies assessing the cause and impacts of RTAs reveal that each accident event is rarely a result of one unique factor but rather a consequence of failure in the human-vehicle-road environment interaction. Under these three broad categories are specific risk factors that contribute to the occurrence of RTAs and worsen the severity of injuries; (Agbonkese *et al*. 2013), for example, a combination of factors responsible for RTAs could be; driving on a slippery road under the influence of alcohol and drugs without wearing a seat belt. Despite the interactions among related accident factors, human error is often the most cited (Scheper *et al*. 2014). In addition, studies also show that demographic, economic, sociocultural, climatic and regulatory factors are closely linked to the human-vehicle-road environment interaction (Hermans *et al*. 2014).

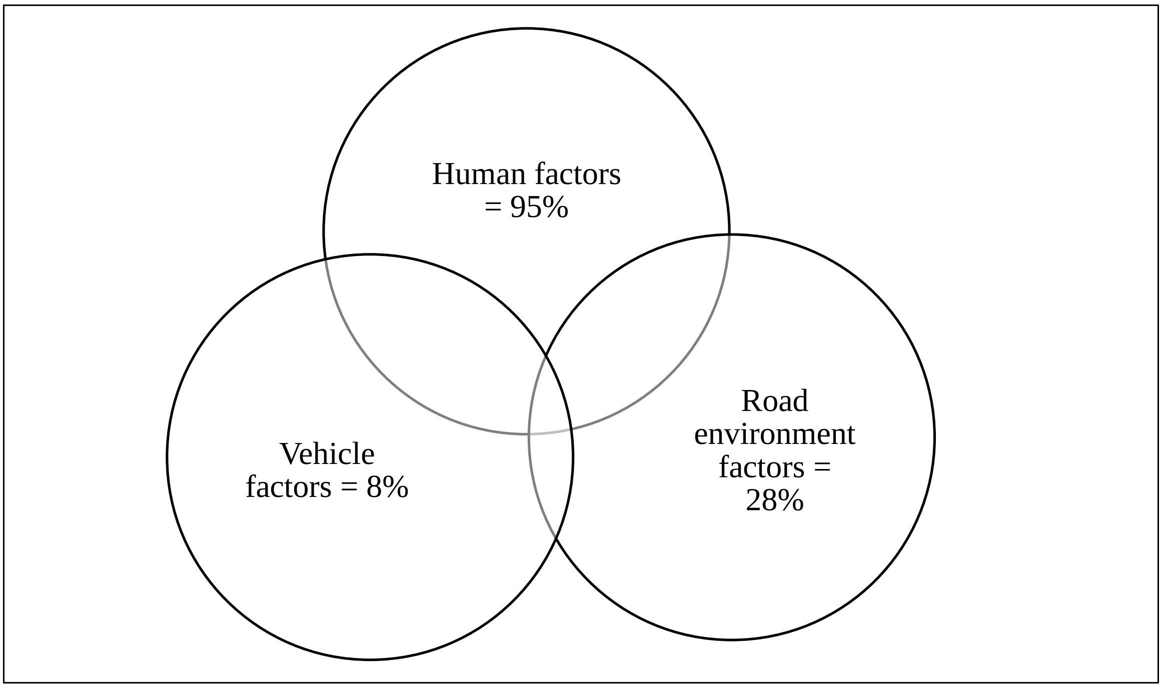

Figure 2.1 A Generalised Model on the Causes of Road Traffic Accidents (Source: Austroads, 1994).

2.3.3 Exposure-Risk-Injury Relationship

In combination with the human-vehicle-infrastructure relations, some studies assert that the degree of exposure and risk (probability of injury) are among the most important factor for road safety (Oluwole *et al*. 2014). People are exposed to risk in traffic because they travel and because there are dangers present in traffic. People travel between locations of activities to perform activities such as recreation, education, working and shopping while others travel because they own a vehicle or a driver's license thus exposing themselves to risk in traffic participation (Schepers *et al*. 2014). Furthermore, Olowule *et al*. (2014) add that exposure to traffic risks results to injuries with varying levels of severity depending on the amount of energy released during the crash impact.

Hermans *et al*. (2008) highlights several exposure estimates, maintaining that their best measure depends on the issue being studied. Among others, those frequently used are the size of the population (number of inhabitants), the number of registered vehicles on the road, the length of the road network and the number of licensed drivers. Oluwole *et al*. (2014) argued that the number of trips or the time in traffic is considered the most relevant measure for exposure. Nonetheless, these indicators do not always act as good measures of exposure due to differences in socio-economic conditions, population density, vehicles per citizen and transport mode split (Al Haji, 2005).

2.3.4 Haddon matrix - Systems Approach

Each transportation system is highly complex and can be risky for human health. In order to make this system less hazardous, Rosolino *et al*. (2014) assert that it is imperative to evaluate the interactions among its prospective dangerous variables by means of a comprehensive approach that may be helpful also for an adequate identification of interventions. The approaches already discussed unpacked road safety in human-vehicle-road environment interaction and exposure-risk-injury relationship. Though informative, these frameworks operate on a linear basis as they narrow RTAs to result from simplistic and straightforward causative factors, hence the need to shift to a non-linear approach. An attempt to define road safety from a systems perspective was developed by Haddon (Peden *et al*. 2014). The systems approach emphasises on the interactions amongst the various distinct elements of the traffic system. Haddon defined three phases of the time sequence of a crash event (pre-crash, crash and post-crash) together with the human-vehicle-road environment interaction during each phase of a crash. The resulting nine-cell Haddon Matrix shown in Table 2.1 "models a dynamic system with each cell allowing opportunities for intervention" to reduce RTIs (Peden *et al*. 2014: 12). This system is applicable at the micro and macro level to analyse processes that produce road crashes and to understand how the transport systems works (Muhlrad and Lassarre, 2005; Agbonkhese *et al*. 2013). Building on this approach, Zein and Navin (2003) further modified the Haddon matrix into what is known as the C3-R3 systems approach.

Table 2.1 The Haddon Matrix (Source: Peden *et al*. 2014: 13)

Phase		**Factors**		
		Human	Vehicle	Road environment
Pre-crash	Crash prevention	Information, attitudes, impairment, police enforcement	Road worthiness, lighting, braking, speed management	Road design and road layout, speed limits, pedestrian facilities
Crash	Injury prevention during the crash	Use of restraints, impairment	Occupants restrains, other safety devices, crash protective design	Crash protective roadside objects
Post-crash	Life sustaining	First aid skill, access to medics	Ease of access, fire risk	Rescue facilities, congestion

2.3.5 C3-R3 Systems Approach

The fundamental building blocks of the C3-R3 systems approach are:

- Three entities: humans, vehicles and road environment
- Three pre-crash timeline stages which affect accident frequency or C3: creation, cultivation and conduct
- Three post-crash timeline stages which affect accident severity or R3: response, recovery and reflection

The pre-crash timeline according to Zein and Navin (2003: 6) is divided into three phases (the three "Cs"), while the post-crash timeline is also divided into three phases (the three "Rs") explained below:

(a) Creation is the phase when an entity is "born" and its initial characteristics are set.

(b) Cultivation is the phase when an entity develops and matures, and its operational characteristics and habits are formed.

(c) Conduct is the phase that represents the entity's actions and conditions immediately before a crash occurs.

(d) Response is the phase where the entity responds to the crash immediately after its occurrence.

(e) Recovery is the phase where attempts are made to recover from the crash

(f) Reflection is the phase where humans look back on the events of the crash in an attempt to prevent future re-occurrence.

The C3-R3 Systems Approach developed by Zein and Navin (2003) is a modification of the Haddon Matrix. It provides an improved systematic framework that clearly defines the phases at which traffic safety professionals can intervene to promote safety. The C3-R3 System Approach emphasises on the convergence of the elements as the timeline advances towards a crash event and their consequent re-divergence in the post-crash timeline. As in the Haddon Matrix, each combination of an element and timeline phase represents a cell in the C3-R3 System Approach. This approach acknowledges the more complex nature of the occurrence of RTAs where human-vehicle-road environment factors interact. This gives room for a multidimensional approach to develop improved traffic safety strategies and hence the relevance of adopting the systems approach for this study to analyse the spatiotemporal distribution of RTAs in Durban.

Table 2.2 C3-R3 Systems Approach (Source: Zein and Navin, 2003)

		Entity		
Timeline		Human factors	Vehicle factors	Road environment
Pre-crash	Creation	Birth environment, gender, social customs	Design guidelines, vehicle purpose, manufacturing, marketing	Guiding policies, planning & design guidelines, planning & design process, construction
	Cultivation	Age, education, training/ licensing, traffic habits, social pressure	Operation, maintenance, repair, modification	Operation, maintenance, information systems, enforcement
	Conduct	Physical and mental condition, distraction, specific decisions	Performance of brakes, wipers, tires, headlights	Traffic volumes and mix, weather, road surface, lighting
CRASH				
Post-crash	Response	Re-examine event, legal action, re-training, change habits, insurance impacts	Trend analysis, safety improvements, insurance impacts	Trend analysis, safety improvements, design guidelines, enforcement
	Recovery	Diagnosis, physical rehabilitation, medical care, mental recovery	Vehicle inspections, vehicle repair, disposal	Event re-construction, road inspection, repair
	Reflection	Crash expectancy, physical strength, first aid, transport	Safety devices, structural integrity, crash detection, towing	Severity control, crash detection, emergency response, traffic control

2.4 Road Safety Risk Domains

The road safety risk domains relates to the importance and contribution of each risk domain in the road safety system. In general, the risk domains are considered to be the central themes of road safety which can lead to improvement in the level of road safety (Hermans *et al*. 2008). Injuries due to RTA depend on a number of factors in which human, vehicle and environmental factors play vital roles before, during and after a serious RTA. The significant factors are human errors, driver fatigue, poor traffic sense, poor condition of vehicle, speeding and overtaking violation of traffic rules, poor road infrastructure, traffic congestion, and road encroachment (Soltani and Askari, 2014). In terms of accident severity, driving speeds are of major importance as well. Environmental factors include the condition of the road network, road type and design, spatial context (density and land-use), temporal context (e.g. darkness) and transport context (traffic density, speed and behaviour of other transport users). Social and psychological factors include socio-demographic and socio-economic structures, risk attitudes, lifestyles, 'mobility styles', and associated behaviour (Holz-Rau and Scheiner, 2013). The road safety risk domains include: age, gender, speeding, driving under the influence of alcohol or drugs, health conditions, fatigue, distracted driving, non-use of safety device and negligence of duty by government established agencies, engine functionality, vehicle carrying capacity, brakes, tyres, lighting, weather conditions, road design construction factors, road signs and markings, and traffic signals. These will be discussed under their respective categories split into human factors, vehicle factors and road environment factors.

2.4.1 Human Characteristics

Driving is a complicated system in which a large number of variables mutually interact with each other with varying degree of dependence. Behaviour is an intrinsic part of people in which individuals possess unique characteristics such as age, gender, education, socioeconomic status and driver training experience (Komba, 2006; Hermans *et al*. 2008). Other influencing factors include driving under the influence of alcohol and drugs, health conditions and fatigue. Altogether, these characteristics affect people's perception, attitudes, driving behaviour and vulnerability towards traffic accident risk. Accidents may be due to human behavioural errors such as judgement errors, ignorance, incompetence, rule violation, negligence (Hermans *et al*. 2008). Achieving reduced accident frequency and injury severity requires alerting and coordinating both the physical and psychological senses properly as a great deal of vehicle control depends on much of these behaviours.

2.4.1.1 Age

The driver's age is known to be a key factor contributing to the occurrence of fatal accidents. Various studies claim that young drivers and novice are frequently involved in traffic accidents in comparison to the elderly drivers (Peden *et al*. 2004; Muviringi, 2012; Agbonkhese *et al*. 2013). This is because young and beginner drivers lack risk perception skills in specific manoeuvres, they have not developed the ability to efficiently perceive or predict risks while driving under inappropriate speed and they lose control of the vehicle in traffic jams compared to other age group of drivers (Muviringi, 2012). Studies also show that, in developing countries, a large proportion of young and beginner drivers learn their skills in apprenticeship with other professional drivers (Chiduo and Minja, 2001; Muhlrad and Lassarre, 2005). Such practices increase an individual's confidence levels, which is actually a powerful source of bias in the perception of risk thus resulting in increased risk of crashes contributing to high fatalities or injuries (Komba, 2006; Trivedi and Rawal, 2011; Agbonkhose *et al*. 2013; Kar *et al*. 2015). Apart from the young and novice drivers, studies have also revealed that drivers aged 70 years and above are also involved in high fatality or injury accidents due to the deterioration of coordinating systems (Agbonkhose *et al*. 2013).

2.4.1.2 Gender

Males are said to be more prone to getting involved in motor accidents than females (Agbonkhose *et al*. 2013). Moreover, males are susceptible to higher risks of experiencing fatal crashes yet their female counterparts are largely involved in higher rates of injury crashes. A possible reason for this is that males are traditionally exposed to traffic risks due to the belief that driving as a profession is mostly dominated by men or due to their involvement in various activities such as travelling to work and social hubs such as beerhalls/ pubs (Al-Haji, 2005; Agbonkhose *et al*. 2013). However, this trend is changing as more females now take part in previously male dominated activities increasing their exposure to traffic risks (Al-Haji, 2005).

2.4.1.3 Speed

Excessive speed is identified as a highly important factor directly related to both the number of accidents, injury severity rates and property damage (Hermans *et al*. 2008; Agbonkhose *et al*. 2013). Al-Haji (2005) and Muviringi (2012) assert that the likelihood of becoming involved in an injury or fatal accident increases with exceeding the speed limit or an inappropriate driving speed in prevailing conditions and that the injury severity rate depends on the deceleration rate and transfer of kinetic energy during impact. Factors cited as influencing the choice of speed are the driver (age, gender, alcohol level and number of people in the vehicle), the design of the road (quality of surface, width and layout), the vehicle (type, comfort and maximum speed limit), the traffic (volume, composition and prevailing speed), the environment (weather, light and enforcement) (Peden *et al*. 2004). Therefore, a significant reduction in traffic accidents and road casualties depends on speed reduction.

2.4.1.4 Drink–Driving and Use of Drugs

Driving under the influence of alcohol increases the probability of accident risk. Alcohol consumption creates the likelihood of compromising a driver's perception, balance and coordination ability to control the vehicle thus leading to taking risky and aggressive behaviour to other road users (Hermans *et al*. 2008; Mabunda *et al*. 2007; Muviringi, 2012). Impairment by alcohol does not only contribute to accident frequency but is also responsible for injury severity rates that result from crashes (Peden *et al*. 2004). Drunken pedestrians crossing the roads have more chances of fatality and sustain more severe RTIs than sober pedestrians, (Muviringi, 2012). Specifically, the relative risk of getting involved in an accident starts increasing significantly at a Blood alcohol concentration (BAC) level of 0.04 g/dl (Peden *et al*. 2004).

Studies also reveal that although alcohol consumption is the prevalent source of driver's impairment, long driving hours cause psychological stress and may lead the driver to use stimulating drugs which are potentially addictive, such as cocaine (Havarneanu *et al*. 2012; Agbonkhese *et al*. 2013). On the contrary, Hermans *et al*. (2008) argue that it is more difficult to quantify the impact drugs have on impairment levels causing driving problems. Nevertheless, it can be expected that drugs intoxication present a higher risk to road safety.

To curb the influence of alcohol and drugs have on road safety, doctors have often advised patients to abstain from driving under the influence of alcohol or drugs as they cause dozing and fatigue (Komba, 2006). In addition, legislation and campaigns on the importance of driving in an alcohol free state have been enacted. However, Chiduo and Minja (2001) assert that campaigns have a tendency to increase knowledge but rarely alter behaviour and in most cases the effects are often temporary as people resort to their old behaviours.

2.4.1.5 Health Conditions

Some medical conditions are also cited to be risk factors for driving. For example, diabetes and epilepsy have been identified as factors that are associated with increased risk if a person is allowed to drive (Bekibele *et al*. 2007). Hermans *et al*. (2008) and EU-OSHA (2010) point out that a number of common medications and acute psychological stress influence driving capacity by lowering concentration levels, alertness and reaction rate thus increasing the probability of accident occurrence and injury severity rates. In addition, under normal circumstances people visit the doctor when they have health issues. However, long distance drivers ignore their health problems and drive with headaches and other impairments or take self-help medication from counters to relieve pain as they do not have sufficient time to see the doctor (Peden *et al*. 2004; EU-OSHA, 2010). As a result, they put themselves at risk of being involved in an accident and affecting other road users.

2.4.1.6 Fatigue

Several studies have shown that fatigue influences driving behaviour in specific ways:

- Slower reaction times in an emergency
- Reduced vigilance for example a fatigued driver will be slower to notice oncoming hazards such as animals, a railway crossing or roadworks.
- Reduced information processing and the accuracy of short term memory (Philip *et al*. 2005; EU-OSHA, 2010)

Conditions likely to increase fatigue related accidents are night driving, inadequate sleep, sleep disorders and prolonged working hours including time spent performing non-driving tasks. Safety Net (2009) and Muviringi (2012) maintain that driver fatigue is common in commercial and public transport drivers due to long hours of work and long distance travelling especially for the cross-border vehicles making them sleep while driving. Possible reasons for exceeding the allowable 8 hours driving distance by commercial drivers while fatigued are incentives given to them for delivering services in time and also the limited number of parking spaces for large trucks in rest areas forcing them to continue with the journey (Komba, 2006; Oluwole *et al*. 2014). Fatigue-related crashes typically involve only one vehicle, which may have veered off the road, and tend to occur at night (Komba, 2006). For other vehicles, fatigue-related crashes often occur on weekends and in the morning at higher speeds than average leading to more severe consequences because of the increased stopping distance. Therefore, it is strongly advisable to plan resting points in advance before embarking on a long journey (Muviringi, 2012).

2.4.1.7 Distracted Driving

Zhang *et al*. (2013) identify a hazard as any possible source of danger from any source or direction, on or near the road that could lead to a crash. These could pose as distractions and include children playing on or near the road, jaywalking, other vehicles suddenly stopping in front of one's vehicle, slippery roads during rainfall (Al Haji, 2005; Sobhani *et al*. 2011).

Agbonkhese *et al*. (2013) further enumerates other practices which pose as distractions to drivers and pedestrians, with a propensity to cause accidents. These include paying attention to billboard signs, receiving phone calls or text messaging, plugging of earphones while listening to music, applying makeup, eating, interaction with passengers and alcohol consumption while driving or walking (Peden *et al*. 2004; Agbonkhese *et al*. 2013). Distractions caused by these factors facilitate longer reaction times in emergency situations such as responding to traffic signals or impaired ability to maintain safer following distances and driving in the correct lane (Oluwole *et al*. 2014). Therefore, it is vital to be alert and adhere to appropriate driving techniques, and also develop the necessary skills in scanning the road so as to better recognise any potential hazards and respond to them adequately.

2.4.1.8 Non-use of Safety Devices and Negligence of Duty by Government Established Agencies

Seat belts and helmets are safety devices provided to safeguard a driver and passengers during an accident (Agbonkhese *et al*. 2013). The use of vehicle seat belts also helps to ensure that the driver is in an upright and comfortable position thus enabling him/her to operate the vehicle in a proper manner. The World report on traffic injury prevention shows that wearing a seat belt reduces the risk of serious and fatal injury by 40-60% while wearing a helmet in motorised two-wheelers reduces fatalities and head injuries by 20-45% respectively (Peden *et al*. 2004). However, safety devices have been grossly neglected thus increasing the risk of fatality or injury among drivers and passengers. The level of injury depends on the impact speed, the type of collision and the sitting position of the casualty (Hermans *et al*. 2008).

Training of drivers increases their driving skills. However, Nyoni (2012) asserts that corruption (bribery) plays a great role in road accidents. Damaged vehicles, unlicensed drivers, over speeding, overloading of vehicles and driving under the influence of alcohol and drugs are some of the crimes drivers get away with on traffic road blocks due to bribery (Nyoni, 2012). A study conducted by Asogwa (1992) in Nigeria showed that a substantial percentage of drivers who possess driving licenses never showed up in any driving school or went through a driving test but simply bought their licenses from traffic officials. As a result of their inexperience, since they were never given any tutorial or taught how to use their vehicles on highways by government accredited driving schools, their decision making ability and reaction speed to traffic is bad (Asongwa, 1992; Nyoni, 2012; Agbonkhese *et al*. 2013).

2.4.2 Vehicle Characteristics

The vehicle itself is frequently cited as a key factor contributing to RTAs and fatality rates or injuries. Factors influencing the risk and severity of accidents include the vehicle design, condition of the steering wheel, defective tyres, safety devices such as the seatbelt, the horn, side and rear view mirrors, wiper blades, braking system, adequate headlights and warning lights, among others, as they affect the driver's ability to maintain control of the vehicle (Agbonkhese *et al*. 2013 and Rosolino *et al*. 2014). Hence, to increase safety chances, vehicle inspections and maintenance should be conducted on a regular basis. During the last decades, many resources have been spent by the automotive industry for enhancing road safety for both drivers and pedestrians (Rosolino *et al*. 2014).

2.4.2.1 Vehicle Engine

The engine is considered to be the heart of the vehicle as it is responsible for bringing other parts of the vehicle into motion such that any sudden failure or breakdown while moving is likely to cause an accident if traffic volume is sufficiently high (Agbonkhese *et al*. 2013). An accident can equally occur if the breakdown is mismanaged when the traffic volume is reasonably low.

2.4.2.2 Vehicle Carrying Capacity

The specific maximum load designed for a vehicle is crucial for determining its stability on the road (Jungu-Omara and Vanderschuren, 2006). The balance point of overloaded vehicles moves to a bad position such that too much weight causes top-heaviness that may cause the vehicle to overturn when negotiating curves in the road (EU-OSHA, 2010; Agbonkhese *et al*. 2013). A study conducted in Papua New Guinea revealed that overloaded vehicles are used to transport passengers thus increasing the risk of accident events (Komba, 2006). Moreover, Schwebel *et al*. (2007) and Peden *et al*. (2014) articulate that most private transport companies exceed the legitimate carrying capacity of their vehicles and make many trips per day to maximise profits. Such practices heighten the likelihood of traffic accidents by creating conditions which permit overturning and rolling back of the vehicle on slopes.

Urban areas are characterised by a mixture of different types of vehicles operating at different speeds. This influences the probability of collisions between the various types of vehicles and non-motorised road users including pedestrians. A collision or crash involving heavy vehicles or overloaded vehicles is more likely to lead to fatalities, slight or severe injuries and property damage on impact (Komba, 2006).

2.4.2.3 Vehicle Brake System

Vehicles use a combination of braking mechanisms such as the handbrake and footbrake which works mutually, with the accelerator as the main synchroniser of the speeds of vehicles (Komba, 2006). Brakes are applied to rotating wheels to reduce the travelling speed or bring the vehicle to a halt. The use of sudden handbrakes and footbrakes often results in overturning of the vehicles (Jungu-Omara and Vanderschuren, 2006). Hence, any fault in the brake system should be taken seriously as a potential source of an inevitable accident and brake mechanisms to be used correctly.

2.4.2.4 Tyres

Tyres are indispensable in determining the stability and safety of vehicles on the road. Due to increased accessibility of cheap tyres, both new and used, it has become a common practice for vehicle owners not to adhere to the manufacturers specifications of tyres into consideration when buying and fitting tyres onto their vehicles (Muviringi, 2012). Incompliance with the manufacturer's specifications has resulted in an increase in tyre bursts sometimes leading to traffic accidents. Apart from not using the recommended tyres, other causes of traffic accidents due to tyres bursts include over or under inflated tyres, load weights exceeding the tyre specifications, poor installation or bad fabrication of tyres and worn out tyre threads (EU-OSHA, 2010; Agbonkhese *et al*. 2013; Jungu-Omara and Vanderschuren, 2006).

2.4.2.5 Vehicle Lights

A fault in the vehicle lighting system has a tendency to mislead other road users creating a propensity for an accident to occur. Vehicle lights are very useful at all times during the daylight, in darkness and in extreme weather conditions for visibility purposes (Pego, 2009). Poor visibility often leads to collisions.

2.4.2.6 Vehicle Maintenance

Once a vehicle is on the road after purchase, its components undergo a process of deterioration, increasing the likelihood of vehicles to be involved in traffic accidents. The number of road worthy vehicles operating in developing countries is lower than those in developed countries (Komba, 2006; Agbonkhese *et al*. 2013). Therefore, performing routine maintenance and pre-start checks is key to ensuring road safety.

2.4.3 Road-Environment Factors

A safe road can be defined as the one that accommodates and compensate for human vulnerability and fallibility (Muhlrad and Lassarre, 2005). Road environment factors include all aspects of weather and lighting conditions, road design construction and maintenance factors, road signs and markings, traffic signals.

2.4.3.1 Weather and Lighting Conditions

Regarding the physical environment, weather is a phenomenon that people do not have much control over as the state of the atmosphere increases or reduces the likelihood of accident occurrence. Weather conditions like rain and mist reduce visibility as the view of the road becomes blurred while floods and geomorphic factors such as rock falls and landslides contribute to accidents (Muviringi, 2012). According to EU-OSHA (2010) and Jung *et al*. (2014), rain reduces the road surface friction force by causing slippery roads, possibly leading to greater likelihood of crash occurrence and increased injury severity. Memchoubi *et al*. (2012) assert that landslides involve great amounts of material which move at tremendous velocity and deposited on undisturbed ground such as roads when they come to rest and destroying everything in their path.

Lighting conditions also influence the occurrence of accidents and also determine the injury severity during impact. Kong *et al*. (1996) and Plainis *et al*. (2006) revealed that a disproportionate number of fatal accidents occur during the night due to the driver's impeded ability to avoid collisions under dim lighting. Other studies have highlighted the strong effect of lighting levels on fatal pedestrian crashes, with pedestrians being three to seven times more vulnerable in the dark than in the daylight (Elvik, 1995; Sullivan and Flanagan, 2003).

2.4.3.2 Road Design - Construction and Maintenance factors

The safety performance of the road transport system is the result of the combination of the functionality, homogeneity and predictability of the network, the road environment, and the traffic involved (Hermans *et al*. 2008). Peden *et al*. (2004) assert that the road network influences accident risk as it determines how road users perceive the environment and offers instructions by means of signals. Road situations, particularly road design attributes, namely road alignment, grade and curvature, section type, traffic-way type, the number of lanes, and speed limit are considerably associated with accident occurrence (Agbonkhese *et al*. 2013). For example, two-way traffic roads increase the probability of higher accident severity due to human perception errors of oncoming or overtaking vehicles on blind spots such as sharp bends

(Schepers *et al*. 2014), while other studies suggest that accidents mostly occur on broader and multilane roads than narrower ones due to increased reckless driving (Komba 2006).

EU-OSHA (2010) add that level grade road sections are positively associated with increased accident severity, while slopes are related to less severe accidents. In contrast, Komba (2006) and Schepers *et al*. (2014) argue that mountainous terrain poses an additional challenge for professional drivers, predominantly on the downhill when trucks and lorries gain momentum and may be difficult to control. Therefore, use of appropriate driving techniques such as engaging to the lowest gear and the correct use of the brake pedal must be applied.

In relation to travel distance, Komba (2006) maintains that travelling long distances to obtain alcohol is significantly associated with increased risk of pedestrian-motor vehicle crashes, if the pedestrian has to cross roads when going back home in a drunken state.

2.4.3.3 Road Signs and Markings

Road signs and markings are an important part of a modern system as they convey substantial safety information and user services. The road signs should be clear by themselves and should convey a definite message to the driver and other road users (Agbonkese *et al*. 2013). Oluwole *et al*. (2014) assert that the installation of curve warning signs reduces accident occurrence by approximately 20% on average. Road signs and markings are crucial for dividing a road into different lanes, assisting the driver in maintaining lateral control of the vehicle, provide visual guidance and aid road categorisation (Chiduo and Minja, 2001). However, these will remain functional and effectively achieve their safety objectives if adequately maintained as they deteriorate with age under sunlight, subject to damage by vehicles and vandalism.

2.4.3.4 Traffic Signals

Traffic signals such as stop signs and give way signs are commonly used as a junction control device in urban areas where they meet capacity and safety objectives by reducing potential conflicts. In their simplest form they operate under fixed time sequence and vehicle actuated (i.e. respond to traffic demands) and increasingly are coordinated to provide control of the network as a whole (Chiduo and Minja, 2001; EU-OSHA, 2010).

2.5 The South African Context in Road Safety

This section provides a brief overview of the patterns and trends in road safety in South Africa as a whole as well as the Government responses implemented to minimise road traffic problems.

2.5.1 Patterns and Trends in Road Safety

Road traffic injuries, fatalities and the promotion of road safety are important policy issues worldwide, in part because road accidents are a big contributor to injury mortality (Plessis *et al*. 2013). While the African Region possesses only 2% of the world's vehicles, it contributes 16% to the global deaths (WHO, 2013a). Nigeria and South Africa have the highest fatality rates estimated at 33.7 and 31.9 deaths per 100 000 population per year, respectively, as shown in Figure 2.2 (WHO, 2013a). South Africa's road traffic fatality rate estimated at 31.9 deaths per 100 000 population exceeds the regional average estimate (24 deaths per 100 000 population) and the global average estimate (18 deaths per 100 000 population) (WHO, 2013a).

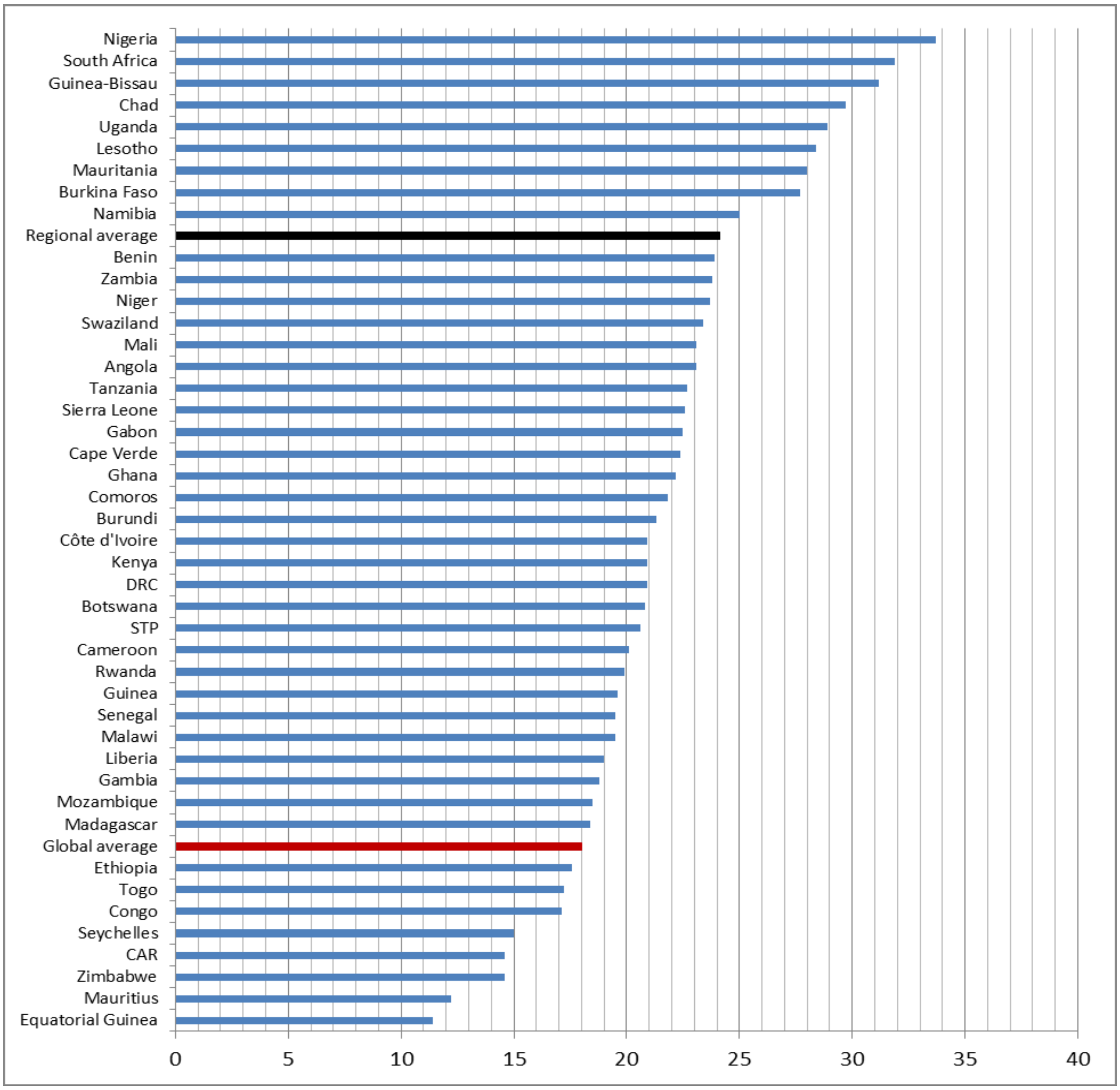

Figure 2.2 Road Death Rates in the African Region in 2010 (Source: WHO, 2013a) where: CAR= Central African Republic; DRC= Democratic Republic of Congo; STP= Sao Tome & Principe.

In addition, du Plessis *et al*. (2013) posit that there has been an upward trend in the number of people killed in road accidents over the period 1935 to 2011 as shown in Figure 2.3 below. It is therefore not surprising that road safety is a priority for the South African government where traffic safety engineers have been working on how traffic safety can be improved through various safety precautionary measures (Choudhary *et al*. 2015).

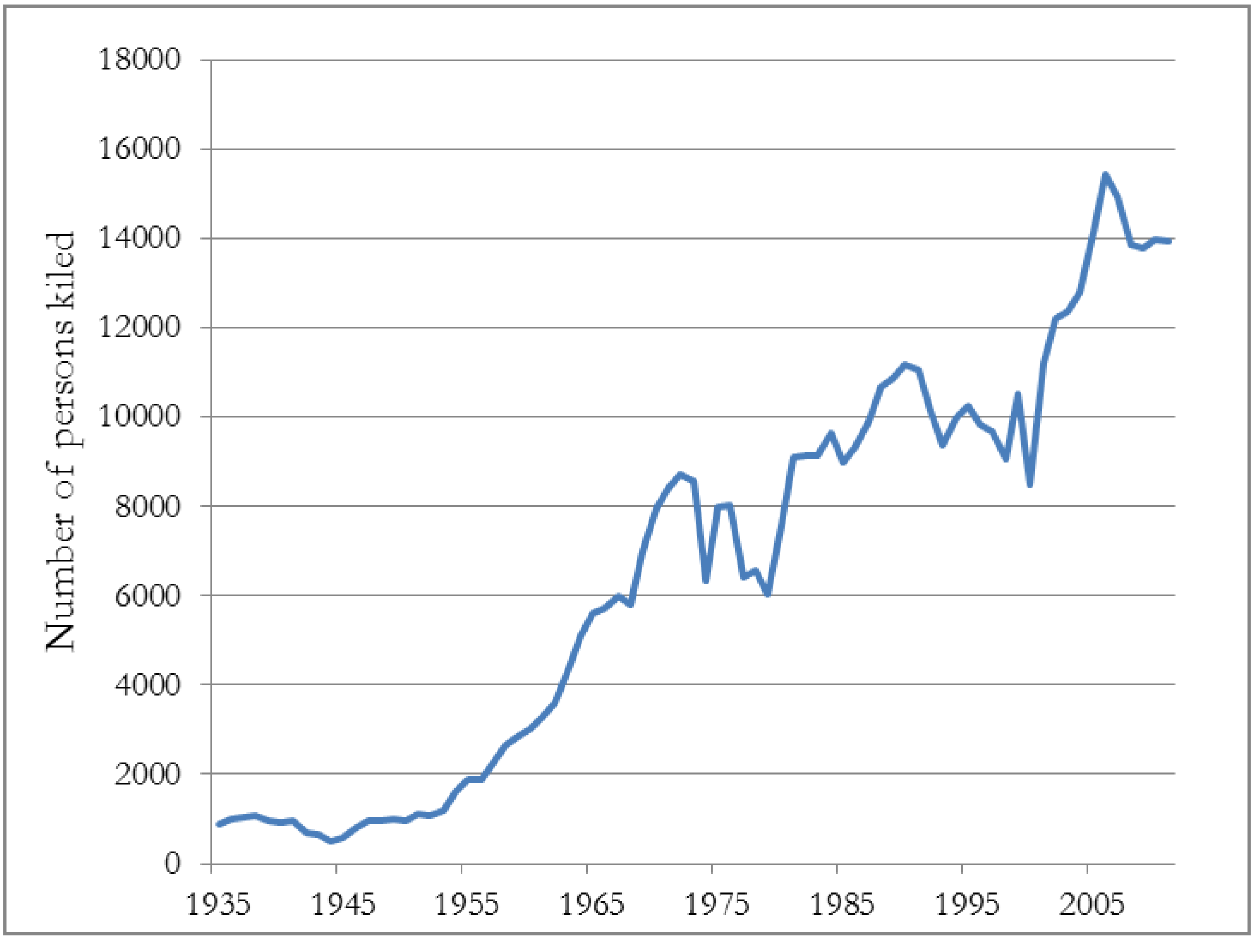

Figure 2.3 Number of Persons Killed in South Africa (1930 – 2011) (Source: du Plessis *et al*. 2013).

The soring road traffic deaths in the country are due to many factors. According to Naumann *et al*. (2010), these include human and vehicle population types and distribution, kilometres driven and the type of road safety policies and interventions applied. In addition, Bester (2001) identifies speed, vehicle ownership, status of infrastructure and the attitude of the driver population as possible explanatory factors for a country's fatality rate. In recent years, South Africa has experienced an exponential increase in the number of vehicles utilising its roads. For example, from 2000 to 2011 (Figure 2.4) a continuous increase in the number of vehicles on South Africa roads was recorded.

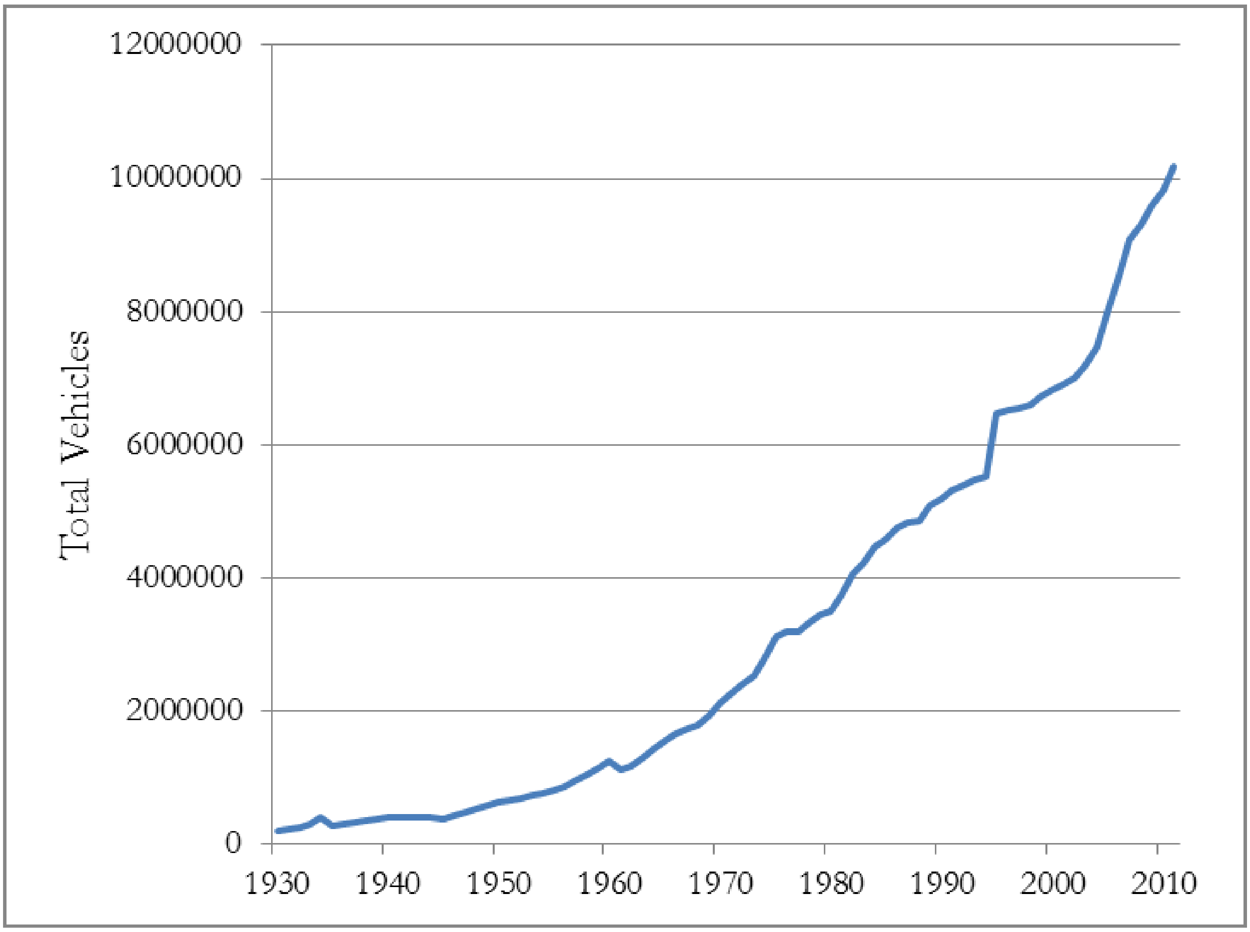

Figure 2.4 Total Vehicles Registered from 1930 – 2010 in South Africa (Source: du Plessis *et al*. 2013).

2.5.2 South Africa's Responses to Road Traffic Problems

Road fatalities remain a serious challenge facing the transportation sector necessitating the need to strengthen interventions to reduce road fatalities. In line with the Decade of Action for Road Safety Resolution of 2010, South Africa is committed to reducing the road fatalities by 50% from the 2010 baseline of 13 967 to 7 000 by 2020, with an expected annual reduction of 700 (Department of Transport, 2015). The following priorities have been identified in line with the Decade of Action for Road Safety pillars (DoT, 2015:21):

- ❖ Intensify efforts to deal with speeding and determine appropriate speed limits
- ❖ Educate people about dangers of irresponsible road usage and the need to be conscious road users by changing behaviour and culture of road users
- ❖ Improve spatial development planning and assess roads in hazardous locations to address road safety

- ❖ Strengthen road worthiness mechanisms to ensure safety of vehicles on the country's roads and compliance to vehicle safety standards
- ❖ Establish data management systems for traffic to strengthen reporting structures and ensure effective monitoring and evaluation

South Africa and several countries around the world have adopted 'The 4 "E" s approach.' The 4 "E" s are: enforcement, education, engineering and evaluation. Parallel to the systems approach, the 4 "E" s approach suggests that in order to reduce the number of RTAs related fatalities, systematic improvements in each of the above-mentioned areas is crucial. Although there are disparities to this approach, this system has been introduced effectively in many countries and it is now regarded among the World's Best Practice (DoT, 2015).

2.5.2.1 Enforcement

Enforcement and traffic laws have more to do with government policy concerning road safety issues. The purpose of traffic regulation systems and enforcement is to ensure adequate operations in the traffic environment and system maintenance by legislation and controls (Jørgensen and Abane, 1999). Regulations by traffic signaling systems, speed limits and speed controls as well as the existence of highly visible police patrols and checkpoints can lead to some reduction of accidents by influencing the road user's behavior. Research shows that high visibility of traffic officers has a 17 minutes positive impact on the behaviour of the road user (DoT, 2015). Given the shortage of enforcement personal in South Africa, those who are deployed make conscious efforts to maximise their visibility and so maintain the perception of widespread enforcement (DoT, 2015).

It is equally important that the public are made aware that if they disobey the rules of the road, they will be caught and they will be punished. A campaign, which concentrated on drunk-driving, seat-belt wearing, vehicle condition and legality, was held between October 2010 and September 2011 in an effort to improve visibility of traffic police and increase awareness on the charges according to the offence done (D0T, 2015).

The challenges in addressing road safety in South Africa are primarily those of human behaviour, such as those of a lack of knowledge of the rules of the road, willingness to abide by the rules, inadequate enforcement and a lack of follow up fines and the resulting culture of impunity in respect to punishment of offenders (du Plessis *et al*. 2013). Another impediment has been the lack of clarity in terms of the line function for road safety with respect to the constitutional division of transport functions among the various spheres of government and the agencies involved in implementation of initiatives such as the Road Traffic Management Corporation (RTMC), South African National Roads Agency (SANRAL), Cross Border Transport Agency (CBTA) and the Department of Transport (DoT) (du Plessis *et al*. 2013).

The Road Traffic Management Corporation (RTMC) is a national agency that was established as a formal institution responsible for road traffic management in South Africa. It was enacted in Section 3 of the Road Traffic Management Corporation Act, No. 20 of 1999 to coordinate all aspects of road traffic management and started its operations in April 2005 (RTMC, 2013). The task of the RTMC is to ensure road safety and promote responsible usage of roads. Its objectives include improvement of the overall quality of the provision of road traffic services by ensuring safety, discipline, order and security on roads, and thereby reducing road fatalities (Adams, 2009). The RTMC planned to reduce the number of road fatalities by 25% during the festive period in December 2012 (Lancaster, 2012) and targeted to reduce fatalities by 50% by 2015 (RTMC, 2010).

The South African National Roads Agency (SANRAL) is an independent statutory company registered in terms of the Companies Act and operates according to the SANRAL and National Roads Act. 7 of 1998. SANRAL's distinctive function is to finance, improve, manage and maintain the national road network. The Cross Border Road Transport Agency (CBRTA) provides service to cross border road transport operators in the form of market access regulation, issuing cross border permits and providing necessary support to the rapidly growing small and medium cross border business focus. The Department of Transport is responsible for regulation of transportation in South Africa, that is, public transport, rail transportation, civil aviation, shipping, freight and motor vehicles.

2.5.2.2 Education

Education refers to road safety education and ranges from awareness campaigns through media, promotional activities and public relations to driver training and education. An estimated 93% access to television (TV) and radio ensures a broad coverage of road safety awareness in South

Africa (DoT, 2015). In line with current social networking platforms such as Facebook, Instagram and twitter road safety awareness has increased. Education projects have been targeted on drivers who are repeat offenders, and also groups who are considered "at risk" such as males between the ages of 18 and 23, public transport users, pedestrians, freight drivers, children and the elderly (DoT, 2015). Over the years, several road safety campaigns have been launched and implemented, and yet the deaths on South African roads are increasing. The most successful decrease in crashes occurred in the Western Cape (17% decrease between 2008 and 2009) and the least successful provinces were Limpopo and Free State, increasing by 9% per year, and KwaZulu-Natal where the crashes increased by more than 7% during the same period (DoT, 2015).

2.5.2.3 Engineering

Engineering focuses on the road and vehicle design, layout and maintenance. A study conducted by Mutto *et al*. (2002) to investigate the effect of an overpass for pedestrians in Kampala (Uganda) found that the construction of the overpass did not lead to a reduction in the number of RTAs involving pedestrians. Although the majority of pedestrians were aware of the overpass's purpose, they refrained from using it because they argued that taking the overpass was time consuming, while other believed it was constructed for children and the elderly (Mutto *et al*. 2002). Similarly, South Africa developed the freeway system with incorporated facilities for pedestrians, cycles and other vulnerable users to support road safety, yet the frequency of serious to fatal accidents occur in those areas. Such findings suggest that construction measures do not necessarily improve road safety unless they are complemented by education and enforcement. Identifying high risk areas and determining whether they are contributed to by the road engineering environment is important so that hazards can be reduced through the provision of traffic calming humps, traffic circles, signs and fences.

Vehicle design and condition are also important. Safety equipment such as seat belts and air bags, and general good condition of brakes, lights, steering wheel and shock-absorbers are vital to ensure safety. Bearing in mind that the average age of the National fleet of vehicles is more than 10 years old, and no regulated vehicles testing takes place, vehicle condition plays a large role in crashes in South Africa (DoT, 2015).

2.5.2.4 Evaluation

According to DoT (2015: 15), the most effective evaluation methods regarding road safety best practice must be scientifically based, with the following questions requiring understanding:

- ❖ Where are the key problems areas and their causes?
- ❖ What road safety interventions are effective in addressing these?
- ❖ Are the interventions effective in terms of the cultures of a particular nation and community?
- ❖ What can be done to improve public awareness and behavioural change?

Monitoring and evaluation is considered to be one of the pillars of international best practice. This is effective where reliable information is available, however, in the South African context, road safety data, capture, processing and dissemination requires further strengthening. Monitoring should include reports on the following basis (DoT, 2015):

- ❖ Measure scale of programmes
- ❖ Asses behaviour shift
- ❖ Monitor safety improvements across areas of roads, users and vehicles.
- ❖ Report on specific enforcement activity across all jurisdictions.

2.6 The Role of GIS in Road Traffic Accident Analysis

GIS is a computer based system for storing, querying, analysing and displaying geographic data, (Longley *et al*. 2005). Spatiotemporal GIS analysis complements and adds value to the traditional methods of identifying accidents patterns in time and space (Asgary *et al*. 2010). GIS techniques have gained impetus and proven to be an effective tool for managing transportation data in other countries (Zovak *et al*. 2014). Its strength as a road accident data management and analysis tool lies in its capabilities and features such as the provision of relational links between various spatial and non-spatial data as well as modelling relations between them (Erdogan *et al*. 2008). Moreover, developing a system that uses GIS to analyse traffic accidents has been pursued towards improving the efficiency and effectiveness of traffic accident countermeasures as the database is easily maintained and updated for further analysis (Deepthi and Ganeshkumar 2010). Also, GIS analysis is less time consuming and less tedious. Hence, GIS enables safety experts to perform and compare different types of analyses including but not limited to density analysis, pattern analysis, spatial query analysis and modelling techniques which prompt the identification of dangerous routes that act as guides to implementing suitable solutions (Oulha *et al*. 2013). GIS capabilities and features improve more conventional road accident data processing and analytical techniques (Olajuyibge *et al*. 2014); provides this study an opportunity to explore how it can be integrated in analysing RTA data in the South African context.

Traffic safety engineers around the world face one of the most imperative questions including where to implement safety precautionary measures so that they can have the most momentous impact for traffic safety (Choudhary *et al*. 2015). Identifying road accident hotspots plays a key role in determining effective strategies for the reduction of high-density accident areas (Anderson, 2009; Truong and Somenahalli, 2011). Efforts have been made to examine road accident hotspot analysis in the academic field and various types of methods for identifying unsafe locations have been developed. However, there is no universally accepted definition of a road accident hotspot (Anderson, 2009). As a result, various researchers describe hotspots, as sites on the section of roads and highways with higher accident frequency (AF), accident rate (AR) and accident severity index (ASI) than expected at some threshold level of significance (Hakkert and Mahalel, 1978; Nicholson, 1999; Kowtanapanich, 2009; Choudhary *et al*. 2015). Geurts *et al*. (2004) detected hotspots by assigning ASI values of 1, 3, and 5 as the weights for a light, serious or fatal casualty of a crash respectively, while Truong and Somenahalli (2011) detected hotspots by computing weights of 3.0 for fatal crashes, 1.8 for serious injury, 1.3 for other injury and 1.0 for property damage only crashes. However, these methods together with other traditional methods, only focus on specific road segments and produce results that are partly dependent on the length of road segment and might not be able to capture hotspots over wide locations (Anderson, 2009).

Some other popular methods for hotspot identification include Empirical Bayes (EB) method, Public Participation Approach (PPA) and Sequential pacing data analysis technique (Hauer *et al*. 2002; Kowtanapanich *et al*. 2005; Mungnimit *et al*. 2009). Among these, EB method is considered a best hotspot identification method (Manepalli *et al*. 2011), although it requires special skills and training in statistical analysis. The EB method is used to detect unsafe locations by developing a statistical model based on the reference population and comparing the expected number of crashes with the observed number (Li and Zhang 2008). Moreover, EB method is more superior to methods such as AF, AR and ASI; however, the later are simple and straightforward thus adopted by many departments of transportation (Mitra, 2009).

Various methods have been developed for point pattern analysis and for detecting hotspots. These methods can be classified under two categories: i) methods which analyse first-order effects, which calculate the variation in mean value of process such as Kernel Density Estimation (KDE) and quadrant count analysis among others; and ii) methods which examine second-order effects that calculates spatial autocorrelation of points for spatial patterns, such as Moran's I Index, Geary C ratio and Getis-Ord Gi* statistics (O'Sullivan and Unwin, 2002). The KDE is one of the most common and a well-established method in identifying spatial patterns and a non-parametric method that involves introducing a symmetrical surface over each point feature, evaluating the distance from the point to a reference location based on a mathematical function, and subsequently, adding the value of all the surfaces for that reference location (Deepthi and Ganeshkumar 2010; Blazquez & Celis, 2013; Xie and Yan, 2013). Planar KDE has been used for hotspot analysis to study highway traffic hotspots (Erdogan *et al*. 2008), to study high pedestrian crash zones (Pulugurtha *et al*. 2008), to study road crash hotspots (Anderson, 2009), to study fatal crash analysis (Oris, 2011) and to study traffic accident hotspots for various roads (Rankavat and Tiwari, 2013). The main benefit of this approach lies in recognising the risk spread of an accident (Anderson, 2009) by calculating the density of events in a neighbourhood around those events allowing some events to weigh more heavily than others, depending on their meaning, or to allow one event to represent several observations (Asgary *et al*. 2010). The major weakness of KDE is its inability to be tested for statistical significance (Anderson, 2009). Spatial distribution of traffic accidents can also be analysed by spatial autocorrelation, which are statistics that simultaneously consider both the location proximity and attribute similarity (Flahaut *et al*. 2003; Soltani and Askari, 2014; Choudhary *et al*. 2015).

The first law of geography states that everything is related to everything else, but near things are more related than distant things (Tobler, 1970). Spatial autocorrelation measures the strength of how features are related and also tests the assumption of independence or randomness (Manepalli *et al*. 2011). If any systematic patterns in the spatial distribution of a variable exists, that variable is said to be spatially auto correlated. If nearby areas are similar, then the spatial autocorrelation is positive. Negative autocorrelation applies to neighbouring areas that are unlike and randomness patterns exhibit no spatial autocorrelation. Spatial autocorrelation also permits the examination of co-variations in properties observed in a two dimensional surface. Spatial autocorrelation indices do not explain why locations that have clusters of statistically significant crashes have higher incidence of crashes than other locations; therefore, spatial autocorrelation methods cannot identify factors that cause crashes (Mitra, 2009).

The two most popular indices for measuring spatial autocorrelation are Geary's C Ratio and Moran's I Index (Nicholson, 1999; Xie and Yan, 2013). These are known as global methods of assessing spatial autocorrelation and they measure and test if patterns of point distributions are clustered or dispersed in space with respect to their attribute values (Mitra, 2009). The main difference between them is either the similarity of attribute values of two points is computed from direct comparison in Geary's C Ratio or with reference to the mean value in Moran's I Ratio (Moons *et al*. 2009; Truong and Somenahalli, 2011). The two indices have different ranges and statistical properties. Moran's I ranges from -1 to 1 such that a positive value indicates clustering while a negative value indicates scattering. Geary's C ranges from 0 to 2 such that values close 0 indicate clustering, while values close to 2 indicate scattering (Truong and Somenahalli, 2011). Unlike KDE, the statistical significance for Geary's C Ratio and Moran's I can be calculated using z-score methods (Erdogan, 2009). Most analysts favour Moran's I as its distributional characteristics are more desirable and this index has greater general stability and flexibility (Mitra, 2009). Moran's I is usually performed to measure the presence of spatial clusters in the data as a requisite for hotspot analysis techniques (Satria and Castro, 2016).

The Getis-Ord statistics can be split into two and generally referred to as the G and Gi* statistics. G-statistics represent a global spatial autocorrelation index and analyse evidence of spatial patterns (Getis and Ord, 1992; Ord and Getis, 1995). The Gi* statistic, on the other hand, is a local spatial autocorrelation index suitable for discerning cluster structures of high or low concentration (Manepalli *et al*. 2011). Getis-Ord Gi* statistics are useful to identify hot/cold spots where features with significantly high/low values must be surrounded by features having simultaneously significant high/low values (Prasannakumar *et al*. 2011; Korter *et al*. 2014). Getis-Ord GI* statistical method has been used to detect statistically significant traffic accident hot spots on various roads and highways by researchers (Prassanakumar *et al*. 2011; Truong and Somenahalli, 2011; Rankavat and Tiwari, 2013).

2.7 Conclusion

This Chapter has presented a theoretical review of literature on different theories, concepts and factors related to the occurrence of RTAs. There has been a shift from linear methods of traffic safety management towards systematic approaches. Linear approaches offer a limited scope of analysis and strategies to intervene in the road safety issues. On the other hand, systematic approaches to road safety acknowledge the more complex nature of the occurrence of RTAs where human-vehicle-road environment factors interact. As such, they allow for multidimensional strategies to improve traffic safety issues. The rationale for incorporating GIS for traffic accident analysis in this study is that GIS offers a more effective and efficient platform to perform various analysis such as density and pattern analysis, spatial query analysis and spatial statistics techniques which aid the identification of hotspots. Road safety in the South African context was briefly unpacked. The next Chapter, discusses the methods used to achieve the aim, objectives and answer the research questions identified in this study. It includes the presentation of patterns and trends of fatal accidents in the form of graphs and tables, together with maps and discussion of fatal accident hotspots within the greater Durban City from 2011 – 2015.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The increasing frequency and fatalities of road traffic accidents (RTAs) continue to cause enormous socioeconomic losses to several countries in the world. This has induced the need for strategies that effectively detect the causes and analyse the spatiotemporal distribution of RTAs hotspots for proper intervention. Analysing traffic accident patterns frequently involves large volume of data. The traditional system of traffic accident analysis relies on data stored in a linear record file system, usually missing the spatial reference and distribution of accidents, hence presenting errors in detecting the actual hotspot locations of accidents (Prasannakumar *et al*. 2011). As such, spatial and attribute data generated from traffic accident records can best be combined and analysed within Geographic Information System (GIS). GIS techniques have been employed in developed countries to study road safety, yet its use in the developing countries, particularly in Africa is still in its infancy. The study therefore empirically highlights the relevance of GIS as a tool for investigating the causes and spatiotemporal distribution of RTAs with a view to develop a spatial decision support system for road traffic management in the greater Durban City. Identifying accident hotspots and informing all stakeholders, including drivers, about them can contribute in making the transportation system more safe and comfortable (Rosolino *et al*. 2014). This chapter outlines the materials and methods that the researcher used to obtain, prepare, analyse and present secondary data in order to formulate maps and graphs that depict the spatiotemporal distribution of RTAs in the greater Durban City. A case study research design is adopted as it provides a general guideline of the research methodology. It includes techniques applied to achieve the research objectives and answer the questions posed by this study. It also includes the presentation of spatiotemporal findings of RTA hotspots in the form of maps and graphs. Research tools and instruments are discussed together with the source and content of RTA data, culminating to data analysis and presentation of results. RTA data was obtained from the Durban City Engineers Unit and it provides the spatiotemporal information of RTAs which were mapped using GIS-based techniques to identify RTA hotspots.

3.2 Research Design: A GIS Based Case Study Approach

According to George and Bennet (2005) a research design helps to plan, structure and perform the research in order to maximise the validity of the findings. There are multiple definitions and understandings of the term case study. A working definition relates a case study to an empirical inquiry that investigates a contemporary phenomenon with its real life context (Yin, 2003). In this context Zucker (2009) posits that a case study design must have five components which are: the research questions, research propositions, unit of analysis, a determination of how the data is linked to the propositions and the criterion to evaluate the findings. Merriam (1998) further identified four essential characteristics of a case study including particularistic, descriptive, heuristic and inductive. Particularistic refers to one event, process or situation that is the focus of a study. Descriptive refers to the rich and extensive set of details relating to the phenomena. A combination of particularistic and descriptive results in heuristic because they improve understanding of the phenomena, whereas inductive refers to the form of reasoning used to determine generalisations that emerge from the data (Merriam, 1998).

Yin (2003) argued that a case study research is used for analytical generalisations where the researcher's aim is to generalise a particular set of results to some broader theoretical propositions. In the effort to construct an applicable research design, attempt has been made in this study to include different GIS spatial statistics techniques to generate maps essential for describing the patterns and trends of road fatal accidents in the greater Durban City. A case study approach is a preferred strategy when "how" and "why" questions are posed (Yin, 1994). Anderson (2009) echoes that road traffic accidents, both in time and in space, are not distributed randomly, which often raises questions about their location and the reasons for that location. The spatiotemporal visualisation of RTAs hotspots which result from mutually interacting factors is descriptive in nature as it explains the phenomenon of RTAs distribution in an area. GIS is indeed one tool that is suitable for integrating data and generating maps of RTA hotspots, hence it has the capacity to analyse and enhance road safety. The aim and objectives of this study is to identify, map and examine the spatiotemporal distribution of road traffic fatal accidents by incorporating GIS as a unit of analysis in the greater Durban City from 2011 – 2015. The study is primarily based on RTA data obtained from the Durban city Engineers Unit. It is therefore essential to note that only reported and recorded RTAs was used to generate RTA hotspots maps and graphs. The most fundamental purpose of RTA hotspots analysis using GIS is to identify and generate the information needed to assist the decision makers in implementing appropriate actions to prevent and to reduce the occurrence of accidents (Anderson, 2009). Figure 3.1 below is a flow chart of the basic steps followed to achieve the aim, objectives and answer the research questions related to this study. Components of this Figure are discussed in the subsections that follow.

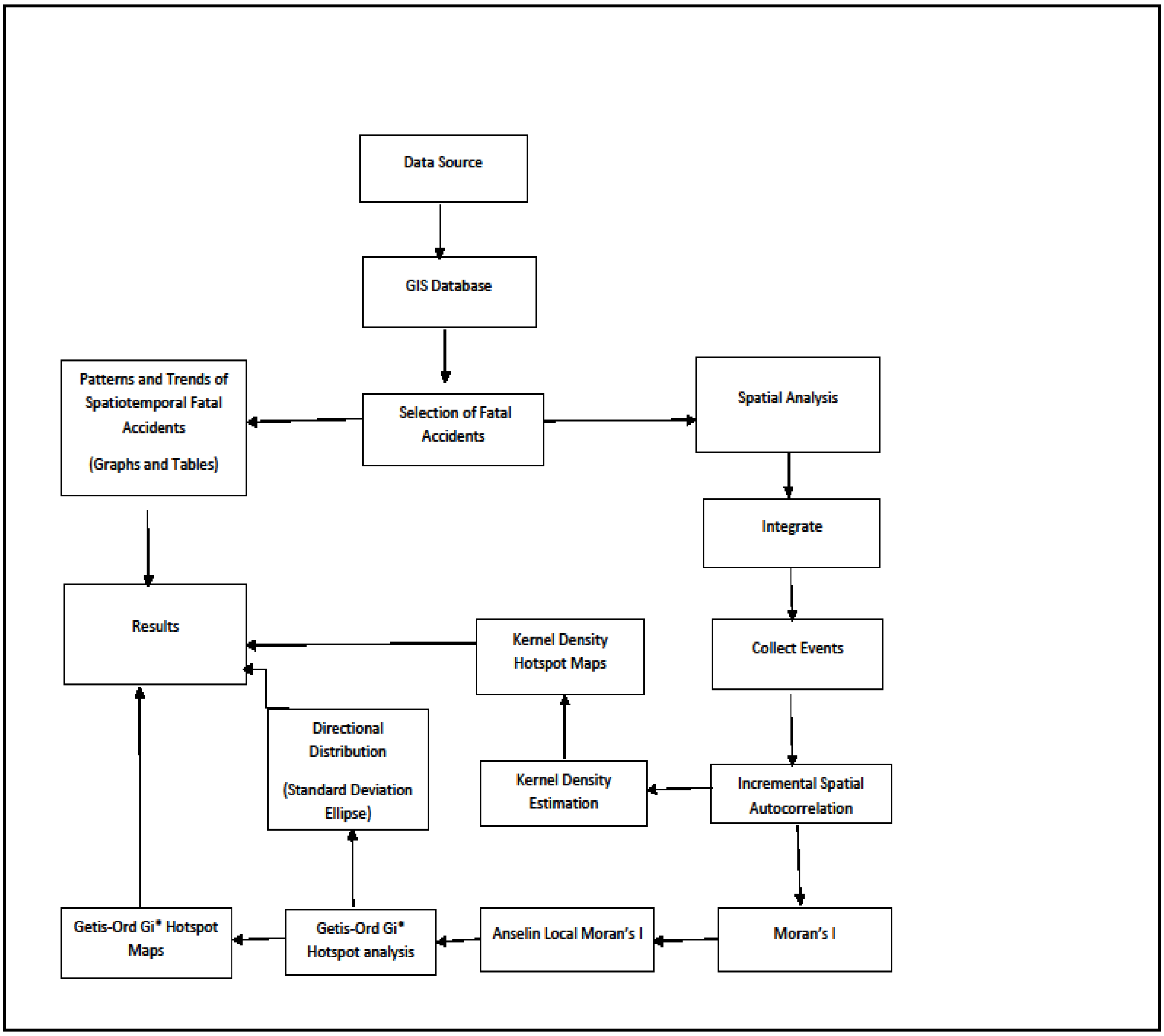

Figure 3.1 A Conceptual Flow Chart of Hotspot Analysis.

3.3 Accident Datasets

The success of preventive actions depends on the traffic accident record analysis. Good quality, reliable and accurate data are needed in order to understand which factors affect road accidents (Rukewe *et al*. 2014). In addition, the spatial location of accidents is a critical aspect of accidents analysis. The RTA dataset used for this present study were obtained from the Durban City Engineers Unit. The datasets represent accident locations geocoded as *x* and *y* coordinates for the period of January 2011 to December 2015. Other spatial dimensions of the dataset include the road characteristics (tarmac or gravel; dual carriage way or single carriage way; dry or wet road surface). The number of pedestrians involved, number of vehicles involved, probable accident cause and accident severity (fatal, serious injury, slight injury or no injury) also make up the dataset. The temporal dimension is divided into five main categories: yearly, monthly, weekly, daily and hourly. The 24 hour of the day is further sub divided into two different periods, namely day & night.

3.4 Severity Index of Accident Occurrence

To determine whether high or low clustering of accidents exists, it is necessary to assign weights to the data. Occurrence of crashes are often used to evaluate safety problems at a location and it is largely believed that the more severe crashes should have greater weights in identifying unsafe locations on the basis of crash costs (Truong and Somenahalli, 2011). However, results from these crash severity method are sensitive to various weighting systems (Geurts *et al*. 2004). Various weighting systems exist with no consensus on how the optimum weighting system should be developed; hence a compromise approach is becoming increasingly popular. The approach is to give weights to the more severe crashes, but not with the extreme high values computed in direct proportion to the crash costs (Truong and Somenahalli, 2011). Geurts *et al*. (2004) assigned the values of 1, 3 and 5 as the weights for a light, serious and fatal casualty of a crash respectively. This research employs an Equivalent Accident Number (EAN) weighting system. It is a method to assign weight factors to crashes by severity (fatal, serious, slight and no injury) to develop a combination of frequency and severity score per site. The weighting factors are calculated relative to No Injury crash costs with an EAN weight of 1, while slight injuries, serious injuries and fatal accidents have an EAN weight of 3, 8 and 12, respectively. This study analysed the fatal accidents only.

3.5 Spatial Data Analysis

Spatial analysis is used to geographically specify the locations where the fatal accidents occurred and to assess specific patterns of distribution through map visualisation. Spatial statistical mapping is the key to understanding the spatiotemporal occurrence of accidents and encompasses a set of techniques for describing and modelling spatial data. Spatial statistical analysis associated with RTAs can be performed on a spatial database incorporating all the selected information and by generating data layers from the available sources updated by field verification. ArcGIS 10.4 spatial statistics tools were used to perform spatial statistical analysis and the generation of maps and graphs. The study area was examined for spatial autocorrelation using Moran's I, Anselin Local Moran's I, and hotspot analysis based on Kernel Density Estimation and Getis-Ord Gi*. Prior to running these analyses, the following steps were taken to determine the appropriate distance threshold: integrate, collect events, calculate distance and Incremental Spatial Autocorrelation. Results from such analysis can help decision makers to identify hotspot locations, which in turn enable the allocation of resources for safety improvements.

3.5.1 Integrate – Collect Events - Neighbourhood Distance

Neighbourhood distance is the spatial extent of the analysis. This value regulates which accidents are analysed together in order to assess local space time clustering, hence, it is necessary to find an appropriate neighbourhood distance where spatial autocorrelation is maximised (ESRI, 2016). ArcGIS's Incremental Spatial Autocorrelation (ISA) tool was used to find the neighbourhood distance for each year. Prior to conducting ISA, the following tasks were conducted. Integrate with the Collect Events tools were used to aggregate the traffic fatal accidents data. The Integrate tool snap incident points together within a specific distance, while Collect Events create a new feature class containing a point at each unique location with an associated count attribute specifying the number of accident occurrences (ESRI, 2016). The resultant ICOUNT field is then used as an input field to calculate distance band from neighbours count.

The ICOUNT field must contain various values because this statistic requires some variability in the features being analysed. If all input values were similar, this tool fails to execute. Calculate distance band, from neighbours count in ArcGIS spatial statistical tools returns three numbers: the minimum, the maximum and the average distance to a specified number of neighbours (ESRI, 2016). The maximum distance is the furthest distance and minimum distance is the closest distance between a feature and its neighbours. The reported average value is the average distance between all the features and their neighbours. The maximum and average values were exploited to find a distance band using the ISA function.

Incremental Spatial Autocorrelation (ISA) creates a line graph of those distances and their corresponding z-scores (ESRI, 2016). The magnitude of spatial clustering is indicated by z-scores. Statistically significant peak z-scores (+1) indicate distances where clustering of traffic accidents is most pronounced. To ensure that all of the aggregated accidents point has at least one neighbour, the maximum value was used as the Beginning Distance, while the average value was used as the Distance Increment as increasing the distance needs to ensure the growth in number of neighbours. The ISA tool runs the Spatial Autocorrelation (Global Moran's I) tool for a series of increasing distances, measuring the intensity of spatial clustering for each distance (ESRI, 2016). An output graph was generated, whereby the X-axis of the graph represents the distance and Y-axis represents the z-score results. At some particular distance, however, the z-score generally peaks. Peaks reflect distances where the spatial processes promoting clustering were most pronounced. One strategy for identifying an appropriate scale of analysis is to select the distance associated with the peak and often this is the first peak (ESRI, 2016).

3.5.2 Moran's I

Moran's I is a commonly used indicator for spatial autocorrelation. In this study, global Moran's I (Moran 1950) was used as the first measure of spatial autocorrelation for fatal accidents. Moran's I evaluate whether the output spatial pattern is clustered, dispersed or random, and determine concentrations levels (Prasannakumar *et al*. 2011). The null hypothesis states that the feature values are randomly distributed across the study area. Moran's Index values range from −1 to 1, and a Moran's Index value near +1.0 indicates clustering, an index value near -1.0 indicates dispersion (Korter *et al*. 2014), while "0" implies perfect spatial randomness (Fu *et al*. 2014). The p-value is a probability, which determines whether the observed values were created by random processes or other underlying spatial processes. The null hypothesis can be accepted when the critical z-score values are ±1.65 using a 90% confidence level, and if the p-value is greater than 0.10 (> 0.10). On the contrary, when the critical z-score values are ±1.65 using a 90% confidence level, and the p-value is less than 0.10 (<0.10) then the null hypothesis can be rejected because significant clustering exists beyond this region (ESRI, 2016). Very high (+2.58) or very low (-2.58) z-scores, associated with very small p-values (0.01) are found in the tails of the normal distribution and these represent clustering or dispersion at a 99% confidence level (Figure 3.2). High z-scores associated with small p-values indicate significant hotspots (shades of red in Figure 3.2), while low z-scores associated with small p-values indicate significant cold spots (shades of blue in Figure 3.2) (ESRI, 2016).

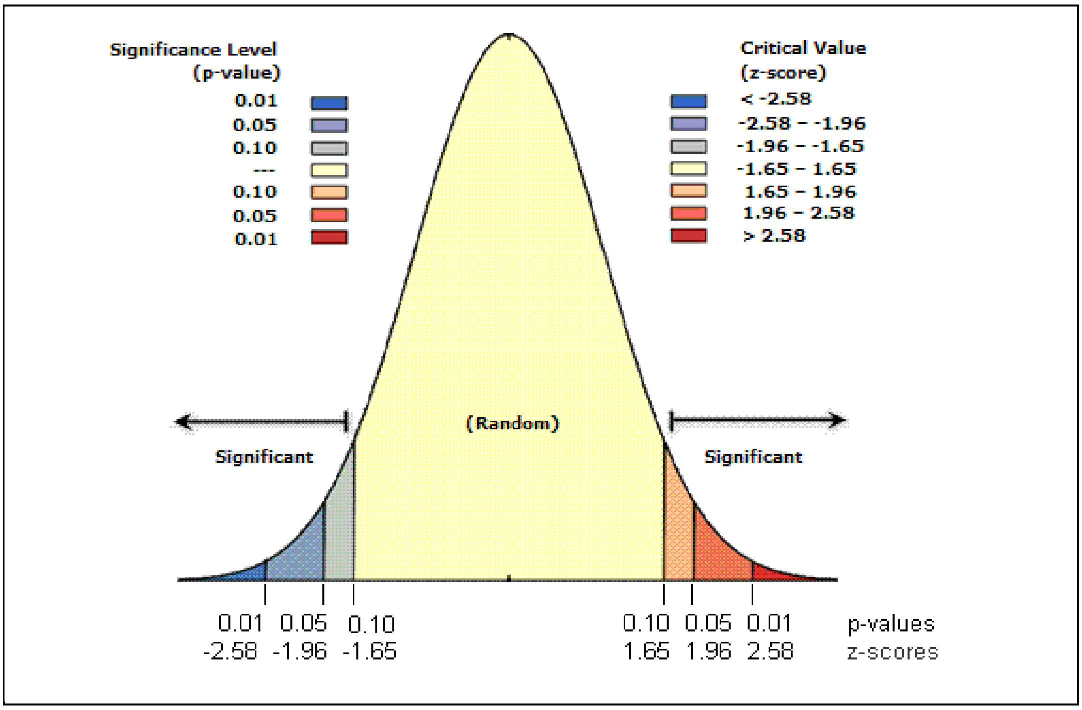

Figure 3.2 Normal Distribution of Global Moran's I values (Source: ESRI, 2016).

The locational proximity of data events were measured as a direct distance between two points while the inverse distance weighting method was used as a measure of locational proximity among neighbouring points (Rukewe *et al*. 2014). Since each data point is analysed in terms of its neighbouring data points defined by a distance threshold, it is necessary to find an appropriate distance threshold where spatial autocorrelation is maximised (Prasannakumar *et al*. 2011). The Spatial Autocorrelation tool was run with different distance thresholds determined by ISA for each year. Moran I-Index is expressed mathematical using the following equation:

$$I = \frac{N\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij})\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where *n* is the number of all fatal accidents in the study area, *xi* and *xj* are the observations at locations of *i* and *j*, $\overline{x}$ is the mean of *x*, and *wij*, an element of spatial weights matrix *w*, is the spatial weight between locations of *i* and *j*.

3.5.3 Anselin Local Moran's I Cluster and Outlier Analysis

While global Moran's I quantifies the spatial autocorrelation as a whole, the local indicators of spatial association (LISA) measure the degree of spatial autocorrelation at each specific location (Anselin, 1995) by using local Moran's I. It is also good for identifying and examining local spatial cluster patterns and spatial outliers (Fu *et al*. 2014; Erdogan *et al*. 2015). Local Moran's I is fully developed by Anselin (1995) as LISA and it is mathematically represented in the following equation:

$$I_i = \frac{n\left(x_i - \overline{x}\right)\sum_{j=1}^{n} w_{ij}\left(x_j - \overline{x}\right)}{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$$

where *n* is the number of all fatal accidents in the study area, *xi* and *xj* are the observations at locations of *i* and *j*, $\overline{x}$ is the mean of *x*, and *wij*, an element of spatial weights matrix *w*, is the spatial weight between locations of *i* and *j*.

The notations in the Local Moran's I equation are as described for the Moran's I equation, but the corresponding values are from the local neighbouring region. With the local Moran's I statistical analysis, five categories of local spatial autocorrelation can be distinguished. Two of these are spatial clusters, including high values surrounded by high values (High-high) and low values surrounded by low values (Low-low) types. Two are spatial outliers, including high values surrounded by low values (High-low) and low values surrounded by high values (Low-high). The last type is the spatial randomness that is without significant spatial patterns at corresponding weight matrix. This study employed the local Moran's I Index to identify the presence of local spatial clustering in the data using different distance threshold generated in ISA for each year.

3.5.4 Kernel Density Estimation (KDE)

KDE is a non-parametric method that involves introducing a symmetrical surface over each point feature, assessing the distance from the point to a reference location based on a mathematical function, and subsequently, adding the value of all the surfaces for that reference location (Levine, 2004). According to Silverman (1986), density estimation is a procedure to create an estimate of the density function from the observed data using the following mathematical expression:

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

Where *n* is the total number of features, *h*, which controls the size of the neighbourhood around *x*, is the smoothing parameter. The function K is called the kernel and it controls the weight given to the observations {*xi*} at each point *x* based on their proximity.

Though several studies exist on traffic accident hotspot detection and analysis, Xie and Yan, (2013) point out that, the kernel density estimation (KDE) approach is the most widely adopted method. Kernel density hotspots with the populated field as GiZScore were performed with the Kernel density calculator function available within the ArcMap software spatial analyst tool at a search radius determined by ISA for each year under review. It calculates the magnitude per unit area from each hotspot features using the populated GiZScore field (Deepthi and Ganeshkumar, 2010). A number of different kernel functions are available, such as Gaussian, Quartic, Conic, negative exponential and Epanichnekov (Gibin *et al*. 2007). This research employed the default Kernel function, Epanechnikov kernel. This kernel function is the most efficient in minimising the mean integrated squared error.

Hotspots can be categorised into six classification schemes: equal interval, defined interval, quartile, natural breaks, geometric interval and standard deviation. In the natural breaks scheme, the classes are based on natural categories inherent in the data and based on Jenks algorithm (Deepthi and Ganeshkumar, 2010). This algorithm is a common method of classifying data in a choropleth map, a type of thematic map that uses shading to represent classes of a feature associated with specific areas. This algorithm generates a series of values that best represent the actual breaks observed in the data, as opposed to some arbitrary classification scheme; thus, it preserves true clustering of data values. Further, the algorithm creates *k* classes so that the variance within categories is minimised (Manepalli *et al*. 2011). The break points are identified by the class breaks that best group similar values and maximise the differences between the classes. The features are divided into classes and creates boundaries that correspond to relatively big jumps in the data values (Manepalli *et al*. 2011). This classification scheme was best suited to the present study in which the output of the Kernel density function is a raster file displaying the areas of low, low-medium, medium, medium-high and high densities of accident occurrence. Lighter shades represent locations with a lower traffic accident density, while darker shades represent locations characterised by the highest traffic accident density.

3.5.5 Hotspot Analysis: Getis-Ord Gi* statistic

The Gi* statistics is a family of statistics that have a number of attributes that make them attractive for measuring dependence in a spatially distributed variable especially when used in conjunction with the Moran's I and Anselin Local Moran's I (Truong and Somenahalli, 2011). Getis and Ord (1995) assert that the Gi* statistics deepen the knowledge of the process that give rise to spatial dependence and enhance detection of local pockets of dependence that may not be detected when using the global statistic. The Gi* statistic is mathematically expressed by the following equation:

$$G_i^* = \frac{\sum_j^n w_{ij}(d) \cdot y_j - W_i^* \cdot \bar{y}}{S \cdot \{[nS_{1i}^* - W_i^{*2}]/(n-1)\}^{1/2}}.$$

Where, *n* is the total number of fatal accident occurrence, *S* is the standard variance of the fatal accidents occurrence ratio, when the distance from location *j* to *i* is within distance *d*, then *Wij (d)* = 1*;* otherwise *Wij (d)* = 0 and *Sij, Wi**. The higher the value of *Gi** is, the greater the influence of location I is at a given distance *d*, indicating that location *i* is a hotspot of the study area.

The Getis-Ord GI* function looks at each feature within the context of neighbouring features (Erdogan *et al*. 2015). The output of hotspot analysis tool is z-score (-1.96 to +1.96) and p-value (± 0.01 to ± 0.10) for each feature. These values represent the statistical significance of the spatial clustering of values, given the conceptualisation of spatial relationships and the scale of analysis (Erdogan *et al*. 2015). A statistically significant positive (1.96) z-score and small p-value (0.05) for a feature indicates a spatial clustering of hotspots, whereas a statistically significant negative (-1.96) z-score and small p-value (0.05) indicates a spatial clustering of coldspots (Erdogan *et al*. 2015; ESRI, 2016). The higher the z-score, the more intense is the clustering. A z-score near zero indicates no apparent spatial clustering (Truong and Somenahalli, 2011). The Getis-Ord Gi* function was run for fatal accidents in the study area for the period 2011-2015. The maximum distance threshold obtained through ISA for each year was used in the Getis-Ord Gi* hotspot analysis.

3.6 Temporal Data Analysis Techniques

There have been a number of studies on the temporal variation of accidents and safety of road sections. El-Sadig and Nelson (2002) studied the variability in quantity and rate of accidents, injuries and fatalities in different time scales such as hourly, daily, monthly and yearly, while Qin *et al*. (2006) employed a hierarchical Bayesian method for estimating temporal variation of accidents in terms of crash occurrence and hourly volume counts for small samples of highway segments. Li *et al*. (2007) also adopted a hierarchical Bayesian approach to estimate relative crash risks by incorporating information from adjacent roadway segments which resulted in a better evaluation of safety for each road section. In this research, the variation of temporal distribution of fatal accidents was determined using simple tables and graphs generated in Microsoft excel. The unit of observation for temporal analysis ranges from hourly to annual basis.

3.7 Conclusion

This Chapter has discussed the research design that enables fulfilment of this study's research objectives and questions. Specific methods discussed include Moran's I and Anselin Local Moran's I to measure spatial auto correlation prior to executing the KDE and Getis-Ord Gi* hotspot analysis in the greater Durban City from 2011 – 2015. Prior to conducting these analysis, Integrate, Collect Events, calculate nearest neighbourhood distance and Incremental Spatial Autocorrelation tools were used to aggregate the fatal accidents data and to determine the appropriate distance threshold for each analysis. The next Chapter presents findings on the patterns and trends of road fatal accidents distribution in the greater Durban City from 2011 – 2015.

CHAPTER FOUR

PATTERNS AND TRENDS OF ROAD TRAFFIC FATAL ACCIDENTS WITHIN THE GREATER DURBAN CITY FROM 2011-2015

4.1 Introduction

Road traffic fatalities are a combined outcome of human behaviour, vehicular and road-environmental induced factors. Concerns about the rising incidence of fatal road accidents compelled the United Nations (UN) into seeking means of curbing road fatalities, hence declaring 2011-2020 as the UN Decade of Action for Road Safety during which all efforts will concentrate on stabilising and reducing global traffic fatalities by 50% in 2020. The Department of Road and Transport, and other government bodies such as SANRAL are responsible for monitoring and ensuring that the goal of road traffic death reduction is achieved by 2020. South Africa, which has the second highest number of road fatalities in Sub-Saharan Africa after Nigeria, will require rigorous efforts to ensure that the UN declaration is not just on paper but is translated to reduce what is happening on the nation's road on a daily basis (RTMC, 2011).

Hence, this study aimed to analyse patterns and trends of road traffic fatal accidents at a local level within the greater Durban City for the period 2011 – 2015. The results presented in this chapter also aid in determining the effectiveness of corrective measures implemented by the Department of Transport at a local level on the reduction of road accidents occurrence.

4.2 Greater Durban City Road Traffic Fatal Accidents from 2011 - 2015

4.2.1 Composition of Road Traffic Fatal Accidents from 2011-2015

Figure 4.1 shows the composition of road traffic fatal accidents within the greater Durban City from 2011 – 2015 during which a total of 546 fatal accidents responsible for 594 victims of fatalities occurred. On overall, there was a slight reduction in road fatal accidents from January 2011 – December 2015, with an average of 109 fatal accidents being recorded annually. The year 2011, which marks the first year of the decade of action for road safety and road traffic accidents recorded the highest fatal accidents (134), followed by 133 in 2012 and 75 in 2013. In 2014, a total of 96 fatal accidents were recorded within the study area while 108 were recorded in 2015. The research findings also show that the year 2013 recorded the lowest fatal accidents within the greater Durban City, followed by 2014. The reduction in fatal accidents from 2011 – 2013 can be explained by rigorous efforts and actions by the Department of Road and Transport together with other road safety agencies within the municipality in response to the mandate from the United Nations to reduce road accidents by 50% (RTMC, 2011). These efforts probably bore fruits resulting to behavioural changes by both motorists and pedestrians in trying to cooperate with and adhere to road safety compliance standards. The effect of behavioural change on road fatal accidents reduction within the municipality correlates to a study done by Sebogo *et al*. (2014), who concluded that road traffic policies on alcohol and change in human social behaviour can be effective in lessening road traffic accidents.

On the contrary, the increasing occurrence of road fatal accidents from 2013 – 2015 can be explained by an increase in the middle-class population resulting from the relatively equitable economic climate which has enhanced spending, culminating to an increase in vehicle population. This interpretation is corroborated by statistics which show that there was an increase of 3.43% in the total number of registered vehicles from 2013 – 2014, an increase of 2.97% in the number of professional driving permits (PrDP's) from 2013 – 2014 and an increase of 4.73% in the number of driving licences in the same period, nationwide (Arrive Alive,n.d). These observations correlates with Oppong (2012), who mentioned that an increase in the number of vehicles would also culminate to an increase in fatal accidents. The increase in the number of PrDP's and driving licences could also be attributed to fraud and corruption where licence holders pay a bribe regardless of limitation in their tested driving skills, and drivers whose vehicles are not road worthy (See Section 2.4.1.8). Another reason for an increase in road fatal accidents in 2013 – 2015 could be non – compliance to road traffic rules by motorists and pedestrians (Nyoni, 2012).

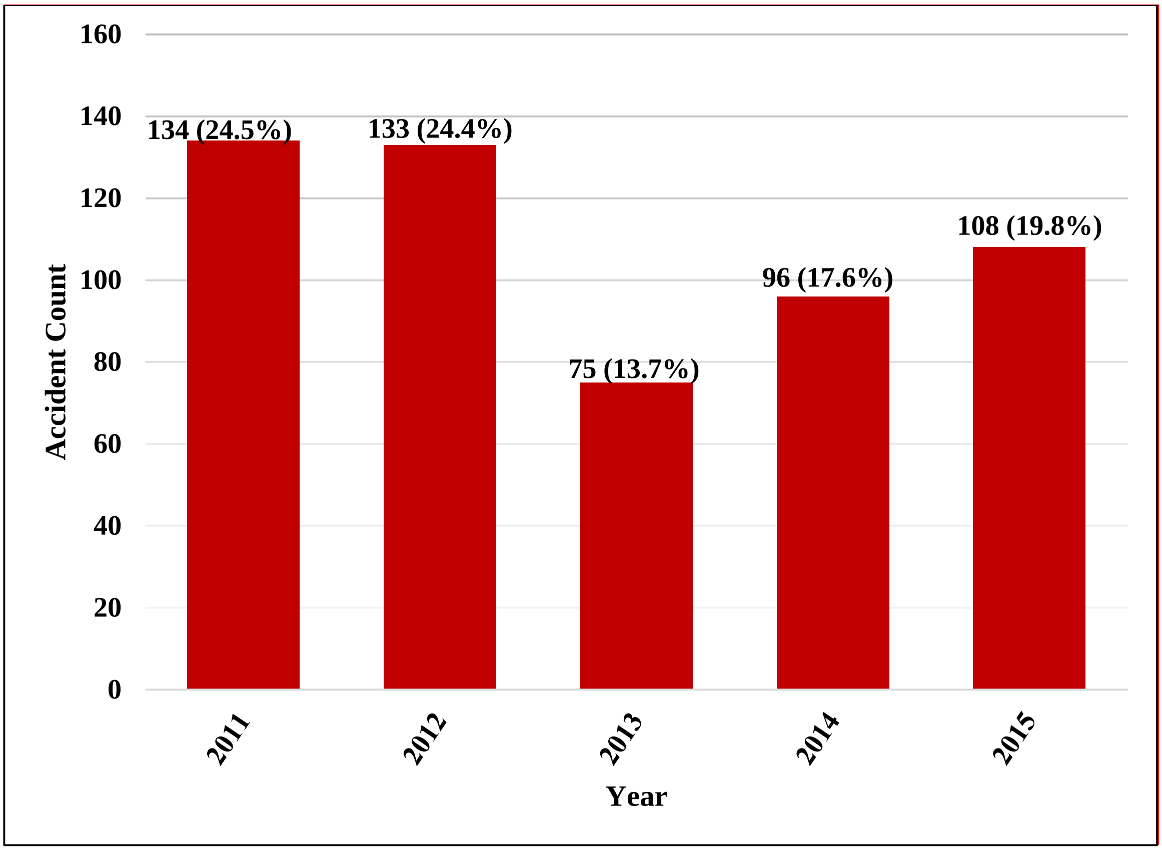

Figure 4.1 Composition of Road Traffic Fatal Accidents from 2011 – 2015.

4.2.2 Fatal Accidents by Time (6-hour interval) from 2011-2015

The occurrence of the road fatal accidents by time of the day was examined. This was categorised into four blocks of 6 hours intervals (Osidele, 2016) to determine the block that recorded the highest number of fatal accidents from 2011 – 2015. The results show that there was an increasing trend of fatal accident occurrence from 01:00am to 00:00pm. The highest (33.3%) fatal accidents occurred in the 18:00 – 23:59 time block, followed by 30.1% in the 12:00 – 17:59 time block, 21.8% in the 06:00 – 11:59 time block, while the lowest (14.3%) fatal accidents occurred in the 00:00- 05:59 time block (Figure 4.2). This trend was also observed in the years 2011, 2014 and 2015 in which 35.8%, 33.3% and 39.8% of highest fatal accidents occurred in the 18:00 – 23:59 time block, as presented in Appendices 4.1a, 4.1d and 4.1e. However, in 2012 and 2013 the highest record (36.8% and 30.7%) of fatal accidents occurred in the 12:00 – 17:59 time block (Appendices 4.1b and 4.1c). Furthermore, Appendices 4.1 - 4.5 suggest that the lowest record of fatal accidents from 2011 – 2013 and 2015 (16.4%, 10, 5%, 16.0% and 11.1%) occurred in the 00:00 – 05:59 time block, while in 2014, the lowest record (16.7%) of fatal accidents occurred in the 06:00 – 11:59 time block. These findings correlates with Oppong (2012), who concluded that the 18:00 – 23:59 time block is the dominant period in which road accidents occurred in Ghana. Furthermore, Clarke *et al.* (2007) mentioned that the majority of fatal accidents in London occurred between 22:00 and 23:59, while the least number of fatalities between the hours of 02:00 and 06.00. The high rate of road traffic fatal accidents within the 18:00 – 23:59 time block can be attributable to commuters who rush home daily to eat, spend time with their families, watch television or get to work on a second job (Pego, 2009). In addition, work related stress and fatigue are likely to contribute to the high fatality rate after 18:00 as the driver's ability to give maximum attention to the road conditions and adhere to road traffic rules at night is reduced (Clarke *et al.* 2007).

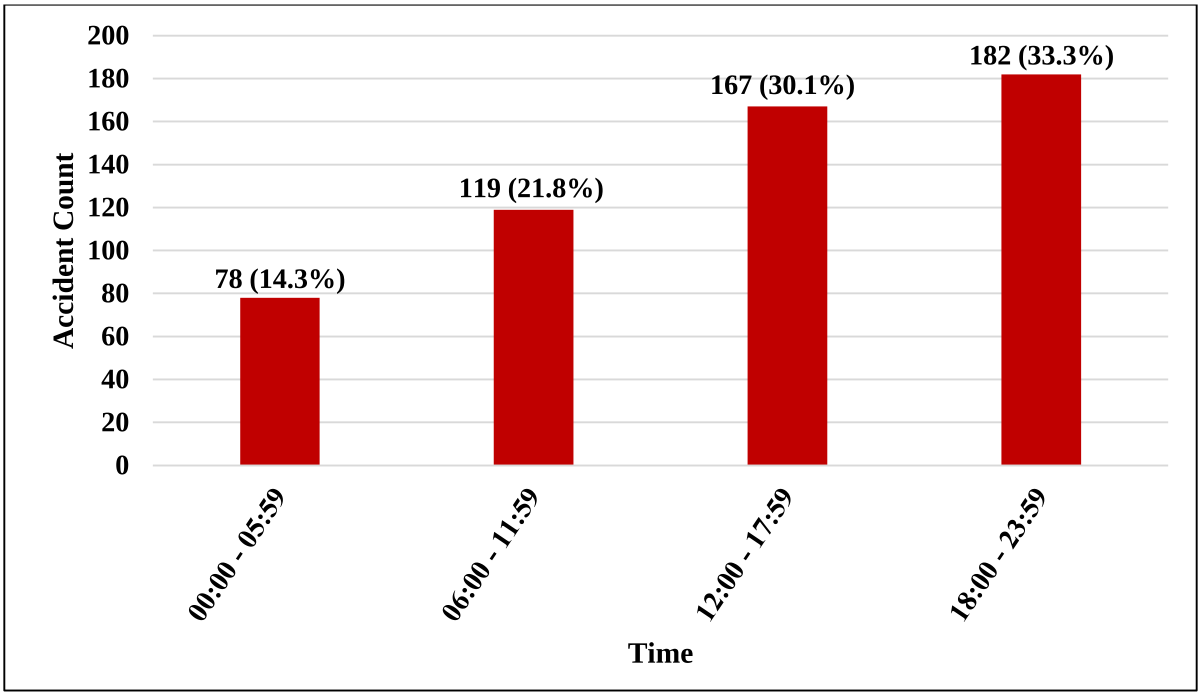

Figure 4.2 Fatal Accidents by Time (6-hour interval blocks) from 2011-2015.

4.2.3 Fatal Accidents by Lighting Conditions from 2011-2015

Lighting conditions during the day plays an important role in evaluating road fatal accidents. The primary data categorised time of day into dawn/dusk, daylight, night (lit by streetlights) and night (unlit). The results reveal that highest fatal accidents occurred during daylight (45.1%), followed by 37.5% during night time (lit by streetlights), 10.8% during dawn/dusk and the lowest record of 6.6% occurred during night (unlit) (Figure 4.3). The year 2011 recorded the maximum (44.0%) fatal accidents during the night – lit by streetlights, while 2012 – 2015 recorded the maximum fatal accidents during daylight (Appendices 4.2a – 4.2e).

Another notable difference was that the lowest (9.3%) fatal accidents in 2015 occurred during dawn/ dusk while the lowest fatal accidents in the period 2011 – 2014 was during the night – unlit (Appendices 4.2a– 4.2e). These findings are consistent with Mokoma (2017), who mentioned that the highest fatal accidents occur during daylight due to an increase in traffic volume and human population, which leads to impatience in all road users and increased aggression among drivers. Aggressive driving encourages drivers to take evasive actions against other vehicles, pedestrians or other objects, to disregard red traffic signals, yield and stop signs eventually causing road deaths (WHO, 2015).

The night times, whether lit by streetlights or unlit, constitute 44.1% of the total fatal accidents recorded in the greater Durban City from 2011 – 2015. The proportion of night time road traffic accidents is almost equal to those recorded during daylight (Figure 4.3). These findings correspond to Clarke *et al.* (2007), who mentioned that slightly under 46% of the fatal accident records examined in London occurred at night. Night time fatal accidents are seemingly high because of an increase in unsafe behaviours such as driving under the influence of alcohol or narcotics, speeding and driving without wearing a seat belt, since the role of traffic police is minimal under such conditions (Komba, 2006); Sebogo *et al.* (2014). In addition, night time fatal accidents are comparably high because it takes longer time for paramedics to receive an accident emergency which is likely to delay the accident victims from receiving first aid and be transported to the hospital due to low traffic flow at night (Komba, 2006).

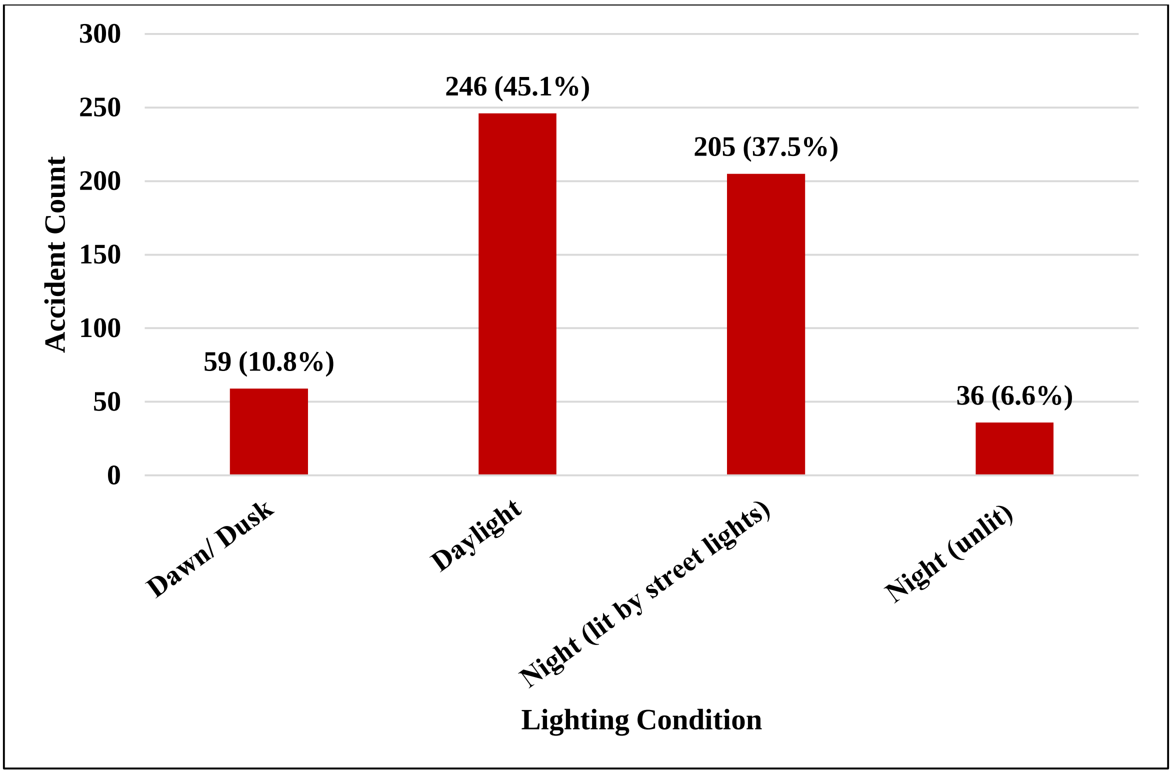

Figure 4.3 Fatal Accidents by Lighting Conditions from 2011-2015.

4.2.4 Fatal Accidents by Day from 2011-2015

The occurrence of road traffic fatal accidents by days of the week was examined. The results reveal that weekends (Friday, Saturday and Sunday) recorded the highest (52.4%) fatal accidents, while the lowest fatal accidents occurred on Tuesday (10.6%), and that Monday and Wednesday recorded the equal number of fatal accidents (12.3%) from 2011 – 2015 (Figure 4.4). Out of the total fatal accidents recorded on weekends, Figure 4.4 summarises that Saturday experienced (20.2%), followed by Friday (16.8%) and Sunday (15.2%). The highest occurrence of fatal accidents on weekends was also observed annually as represented in Appendices 4.3a – 4.3e. It is also evident in Appendices 4.3a – 4.3b and 4.3d – 4.3e, that some peaks records of fatal accidents in each year occurred during weekdays, for an example, Monday accounted for 15.7% of fatal accidents in 2011, Wednesday recorded 15.0% in 2012 and 14.6% of fatal accidents in 2014, while Thursday accounted for 13.9% of fatal accidents in 2015. Tuesday was also the day on which the lowest fatal accidents occurred in 2012, 2013 and 2015, accounting for 11.3%, 5.3% and 11.1%, respectively (Appendices 4.3b, 4.3c and 4.3e).

One can conclude that more than 50% of fatal accidents take place on weekends in thegreater Durban City. These findings corroborate a study by Ukoji (2014), who affirms that 42.3% of fatal accidents in Nigeria from 2006 – 2014 occurred during weekends rather than on weekdays. Weekends are marked by religious and social activities that lead to an increase in traffic flow and human population on the roads, and often lead to fatal accidents (Pego, 2009). Furthermore, alcohol consumption occurs more on weekends, and increases the risk of a fatal accidents on different road users (Sukhai and Nierkerk, 2002; Clarke *et al.* 2007). Return trips on Sundays for drivers who resume official duties at work on Mondays are often marked by fatal accidents as the drivers are likely to be fatigued, which results in poor vehicle coordination due to dozing, or will be in a hurry to reach their destination which encourages over speeding (WHO, 2013).

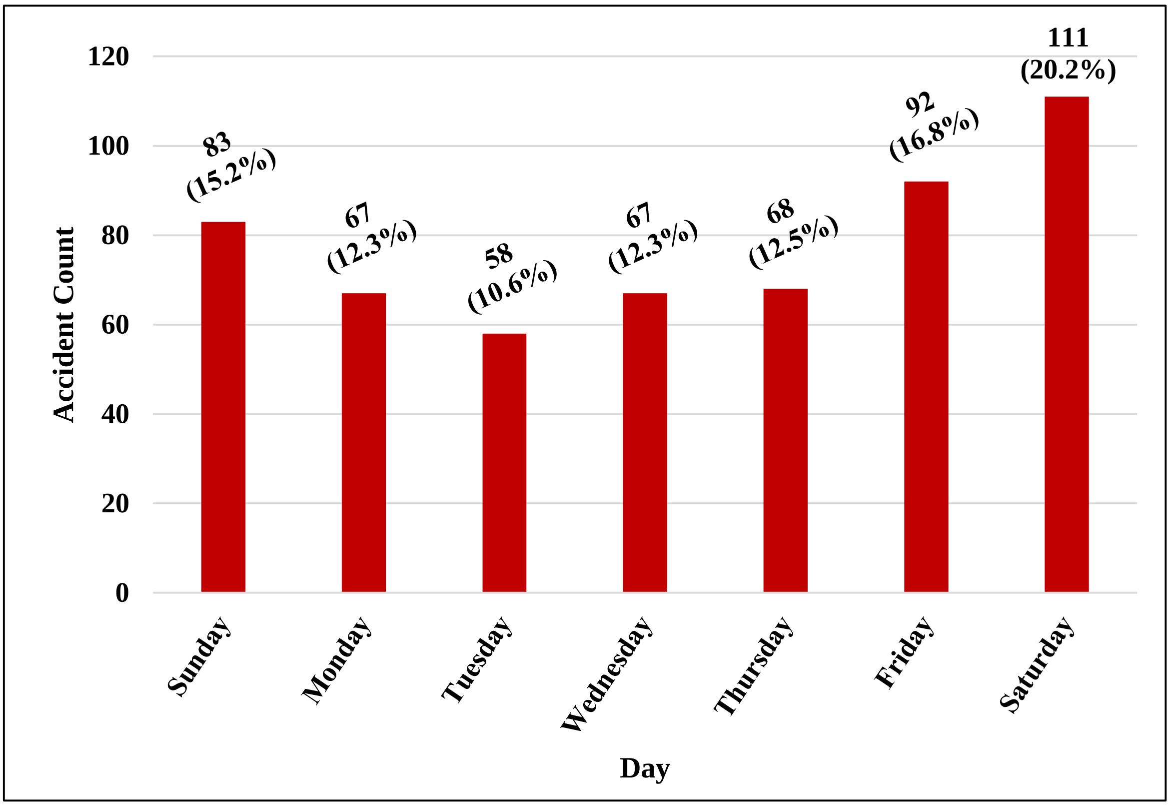

Figure 4.4 Fatal Accidents by Day from 2011-2015.

4.2.5 Fatal Accidents by Month from 2011-2015

The pattern and trend of fatal accidents by month was examined and results shows that the months with the highest fatal accidents record are May and December (10.1%), followed by March and June (9.5%) from 2011 – 2015 (Figure 4.5). November experienced the lowest

(5.0%) record of fatal accidents from 2011 – 2015. On average, 46 (8.4%) fatal accidents were recorded per month from 2011 – 2015 and Figure 4.5 summarises and shows that each month from March – September recorded 46 or more fatal accidents. The months with the highest fatal accident records are marked with increased various economic activities that increase traffic pressure on the roads, which often leads to increased fatal accidents (Sukhai *et al.* 2011). These findings confirm the assumption that most fatal accidents happen during holidays and the festive seasons (Sukhai and Jones, 2013; Ukoji, 2014). Sukhai *et al*, 2011 assert that South Africa has a significant December peak in road traffic accident deaths due to heavy traffic flow from different vehicles and increased alcohol consumption. The festive season in December is also marked by an increase in the number of unlicensed and inexperienced drivers on the road, and drivers who are unfamiliar with local driving settings, reflecting the increased need for travel, which often results in accident injuries or fatalities (Sukhai *et al.* 2011). The greater Durban City hosts local and international tourists during public holidays and the festive season, who are unfamiliar with the roads who contribute to the high record of fatal accidents in the months identified in Figure 4.5. Therefore, effective interventions such as road safety campaigns targeting all road users should focus on behavioural risks to enlighten people on the necessity of safety rules and regulations, during the high-risk months.

The pattern of highest and lowest fatal accidents by month varies between the years under review. Appendices 4.4a and 4.4b reveal that the months with the highest fatal accidents in 2011 were May (13.4%), April (11.9%), July (9.7%) and August (8.9%), whereas in 2012 it was March (12.8%), December (12.0%), April (10.5%) and July (10.5%). In 2013, the highest fatal accidents were recorded in May (13.3%), February (10.7%) and September (10.7%) as shown in Appendix 4.4c. August (12.5%) recorded the highest fatal accidents in 2014, followed by February, March, June, September and December, which experienced 10.4% per month (Appendix 4.4d). The months with high fatal accidents in 2015 were June (14.8%), December (12.0%), July (11.1%) and May (10.2%) recorded the highest fatal accidents (Appendix 4.4e). The months which appeared several times for the highest road traffic fatal accidents occurrence were May, July and December (Appendices 4.4a – 4.4e). The months which experienced the lowest fatal accidents were November (4.5%) in 2011, October (3.8%) in 2012, November (1.3%) in 2013, July (4.2%) in 2014, and January and November with an equal share of 4.6% in 2015 (Appendices 4.4a – 4.4e). These findings correspond with Pego (2009), who identified variations in the months of high road accidents in Botswana and showed that July is as deadly as the festive period of December. This can be attributed to the school holidays and public holidays all over the country (Sukhai *et al.* 2011), hence the need for critical interventions in the specific months.

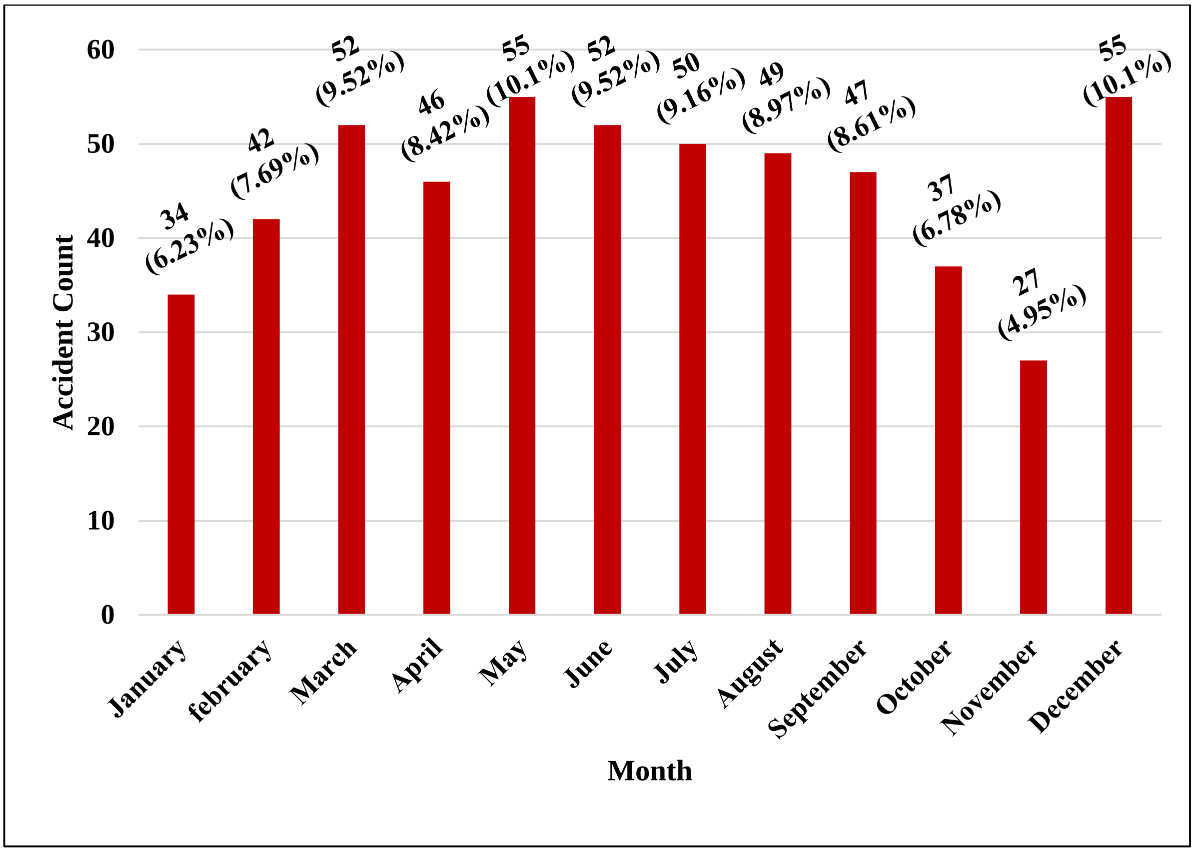

Figure 4.5 Fatal Accidents by Month from 2011-2015.

4.2.6 Fatal Accidents by Weather Conditions from 2011-2015

The influence of weather conditions on the occurrence of fatal accidents from 2011 – 2015 was examined. Results reveal that highest (91.1%) fatal accidents occurred in clear weather conditions, followed by 5.3% in rainy conditions, 2.4% in overcast skies and only 0.4% in unknown weather conditions (Figure 4.6). A similar trend was observed in the different annual analysis as presented in Appendices 4.5a – 4.5e. These findings correlate to Tefft (2016), who mentioned that a majority of all crashes in the United States of America from 2010 - 2014 occurred in clear weather (86.2%). In addition, Eisenberg (2004); Keay and Simmonds (2005); Brijs *et al.* (2008), reported that rainfall was highly associated with an elevated crash risk. Jung *et al.* (2014) posit that rain reduces the road surface friction force by causing slippery roads which increases the likelihood of accident occurrence and increased severity. Although rainy conditions are the second largest in which fatal accidents occurred in the greater Durban City from 2011- 2015, they contribute approximately 86% less than clear weather conditions (Figure 4.6). Therefore, the results revealing lower rates of fatal accidents during rainy periods may be attributable to drivers exercising more caution and driving more slowly in these conditions (Fridstrøm *et al*. 1995).

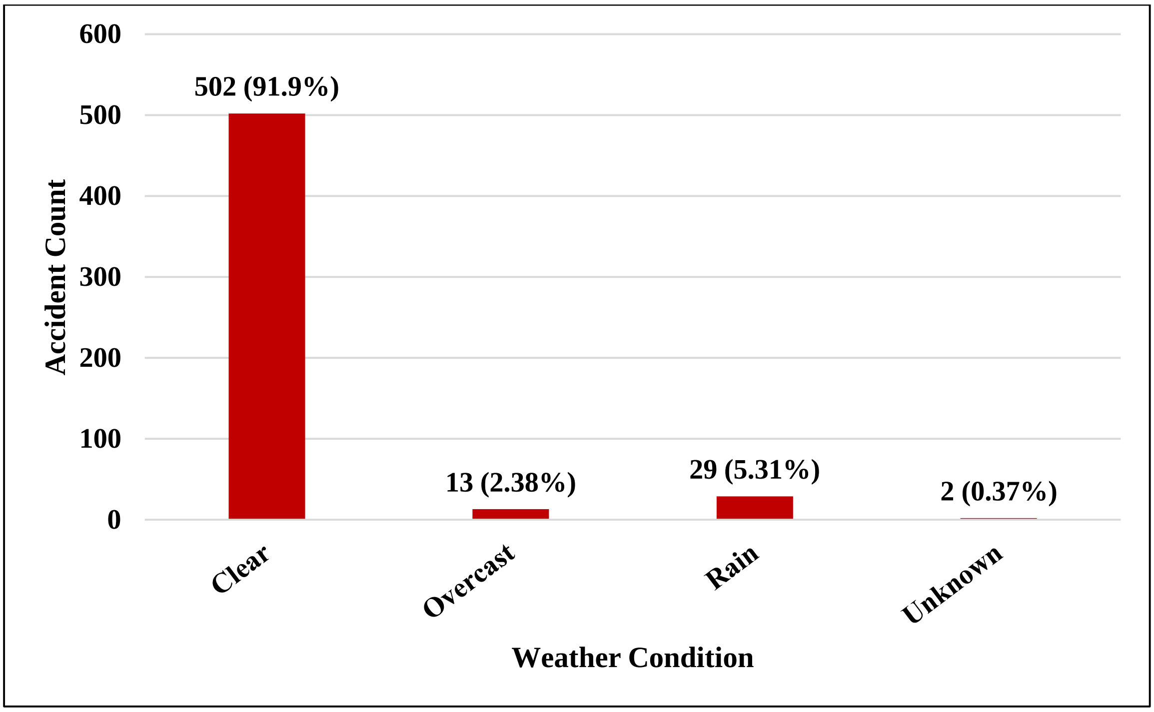

Figure 4.6 Fatal Accidents by Weather Conditions from 2011-2015.

4.2.7 Fatal Accidents by Road Type from 2011-2015

The occurrence of fatal accidents by road type was examined and results reveal three critical road types on which highest fatal accidents occurred from 2011 - 2015. These are dual carriageways (30.4%), freeways (26.7%) and single carriageways (25.8%) as shown in Figure 4.7. Similarly, dual carriageways, freeways and single carriageways are the road types on which the largest fatal accidents were recorded annually (Appendices 4.6a – 4.6e). Also in 2015, the largest share of fatal accidents (34.3%) occurred at single carriageways than at dual carriageways (Appendix 4.6e). These findings correlate with Rukewe *et al.* (2014), who mentioned that of all fatal accidents in Ibadan, Nigeria, dual carriageways accounted for 54.3%, while 45.7% occurred at non-dual carriageways. Dual carriageways account for higher fatal accidents because they host wider roads with more traffic lanes, and these tend to encourage the increase of motor vehicle traffic speed, which increases the risk of an accident occurring (Mokoma, 2017); (ROSPA, 2017). Furthermore, WHO (2013b) articulates that wide roads increases pedestrian injury risk because the traffic speed limit increases accident severity and wider roads with more lanes requires longer crossing time for the pedestrian.

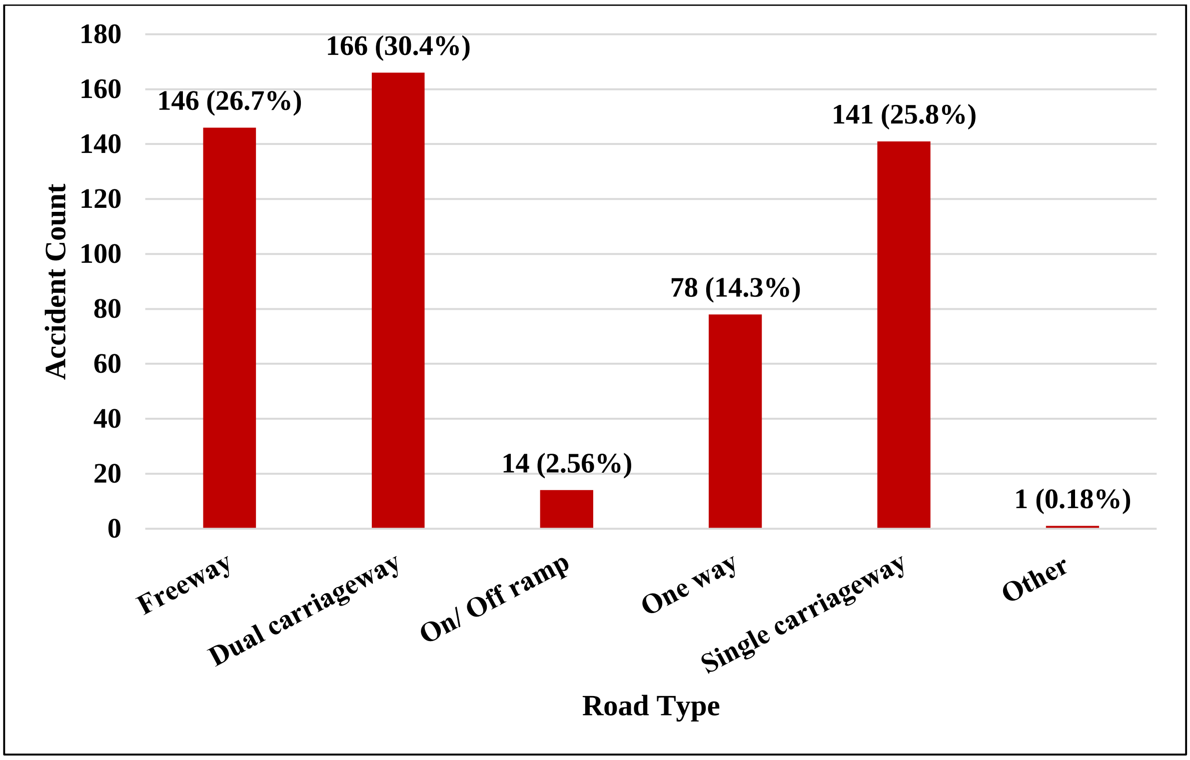

Figure 4.7 Fatal Accidents by Road Type from 2011-2015.

4.2.8 Fatal Accidents by Road Surface Type and Description from 2011-2015

Road surface type determines the severity and frequency of accidents, hence, the occurrence of fatal accidents from 2011 – 2015 was examined. Results show that a majority of fatal accidents occurred on dry roads (93.0%), followed by wet roads (5.7%) (Figure 4.8). Other road surface types on which fatal accidents occurred in the study area jointly account for 1.3% of the total recorded from 2011 – 2015 (Figure 4.8). The same pattern and trend was observed in the annual analysis as presented in Appendices 4.7a – 4.7e. These findings are consistent with Pego (2009), who suggested that most of the accidents in Botswana occurred when the road was dry than when the road was wet. In addition, Teft (2016) established that in the United

States of America 79.3% of accidents occurred on dry roads while 14.2% occurred on wet roads. The higher rate of fatal accidents on dry roads may be attributable to drivers associating a low risk perception when driving on dry tarmac roads compared to the high-risk perception associated to driving on wet road surfaces.

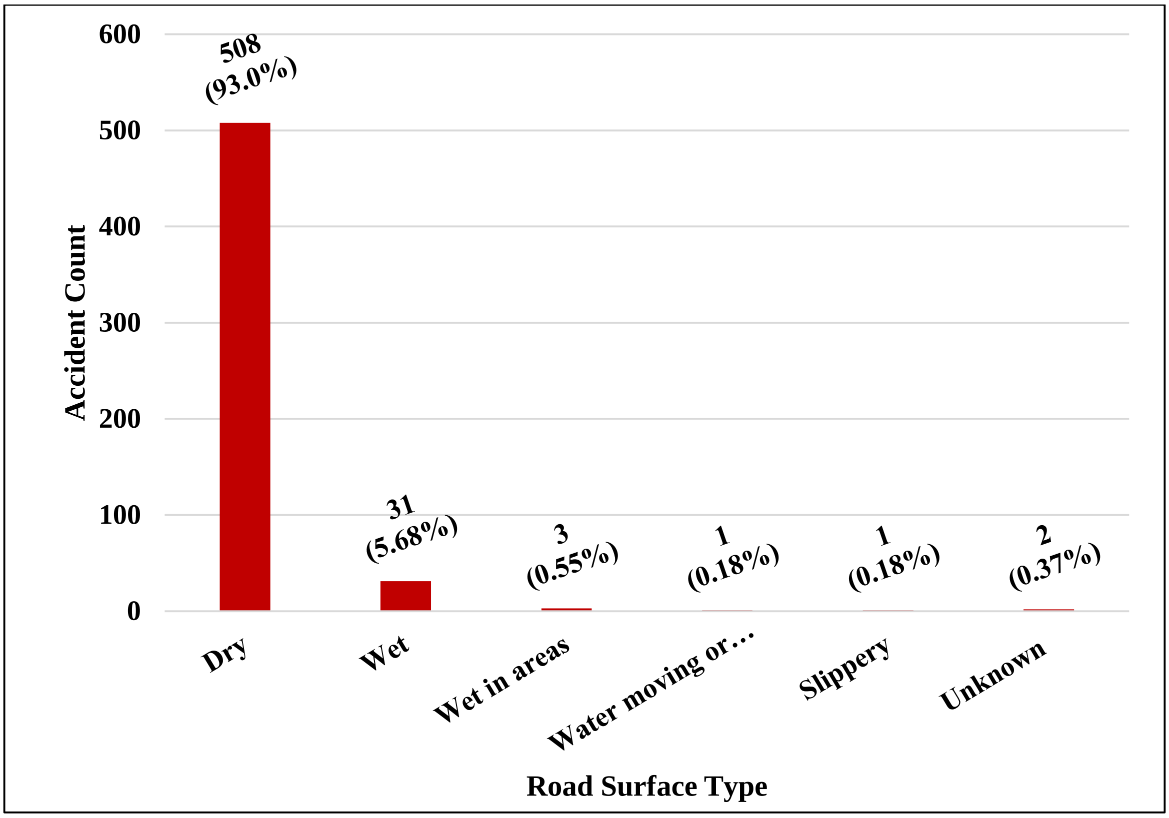

Figure 4.8 Fatal Accidents by Road Surface Type from 2011-2015.

Table 4.1 summarises the occurrence of fatal accidents by road description and shows that 99.6% of fatal accidents from 2011 – 2015 occurred on tarmac surfaces, while concrete and unknown road surfaces jointly contributed to 0.4%. The high rate of fatal accidents on tarmac surface show that the road infrastructure in the greater Durban City is well developed, hence present a common surface at which accidents occur. Fatal accidents on concrete and unknown surfaces were only recorded in 2012, and these can be attributable to road works, which enable traffic congestion to occur and a buildup of impatience among drivers who end up overtaking dangerously, resulting in fatal vehicle-object collisions, vehicle-pedestrian collisions or vehicle-vehicle collisions, among others.

Table 4.1 Fatal Accidents by Road Surface Description from 2011 – 2015

Road Surface description	2011	2012	2013	2014	2015	2011 - 2015
Concrete	0	1	0	0	0	1
Tarmac	134	131	75	96	108	544
Unknown	0	1	0	0	0	1

4.2.9 Fatal Accidents by Junction Type and Junction Control Type from 2011-2015

The influence of junction type and junction control type on the occurrence of road traffic fatal accidents was examined from 2011 – 2015. The results reveal that there is a distinct variation on the occurrence of fatal accidents by road junction type and junction control type. The majority (60.8%) of fatal accidents occurred at portions of the road which is not a junction, followed by 20.1% at crossroads and 12.6% at T-Junctions from 2011 – 2015 (Figure 4.9a). A similar pattern and trend was observed in the individual yearly analysis, with the exception of 2011 whereby the second highest of fatal accidents was at T – junctions rather than at crossroads (Appendices 4.8a – 4.8e). Figure 4.9a also shows that off-ramps recorded 4.0% of fatal accidents, whereas on-ramps recorded 1.8%, staggered junctions recorded 0.4% and 0.2% was recorded at an unknown type of junction. The number of fatal accidents that occurred at off ramp/slipways is twice of that which occurred on ramp/slipways. The higher frequency of fatal accidents outside junctions is probably due to a high number of fatal accidents occurring on dual carriageways, freeways and single carriageways which are designed for long distance trips and heavy traffic flow at higher speeds due to wider and more lanes (ROSPA, 2017). Another possible and worrisome reason for such a high number of fatalities at out of junction roads is that pedestrians cross the roadways at undesignated crossing points where motorists do not anticipate their presence (Jungu – Omara and Vanderschuren, 2006). Such a situation raises panic for the driver and increases the inability of the driver to apply brakes on time resulting in a crash, or when emergency brakes are applied other vehicles become at risks of being involved in a multi-vehicle crash resulting in further loss of lives (van Niekerk, 2006). Fatal accidents on crossroads and T-junctions may be attributable to the fact that drivers and pedestrians disregard red traffic signs at robot-controlled junctions (26.7%) or at a stop sign (5.3%), yield sign (2.7%) and 5.5% at uncontrolled junctions as shown in Figure 4.9b. A similar trend was recorded on an annual basis (Appendices 4.9a – 4.9e).

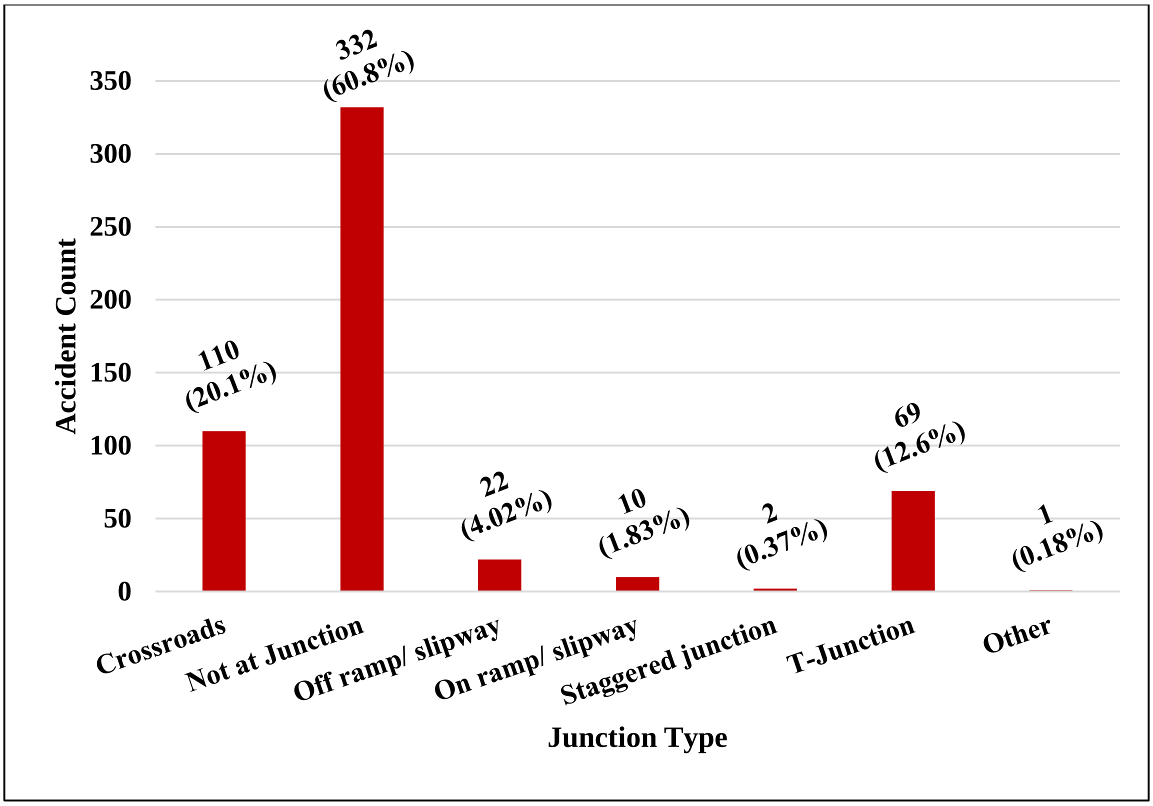

Figure 4.9a Fatal Accidents by Junction Type from 2011-2015.

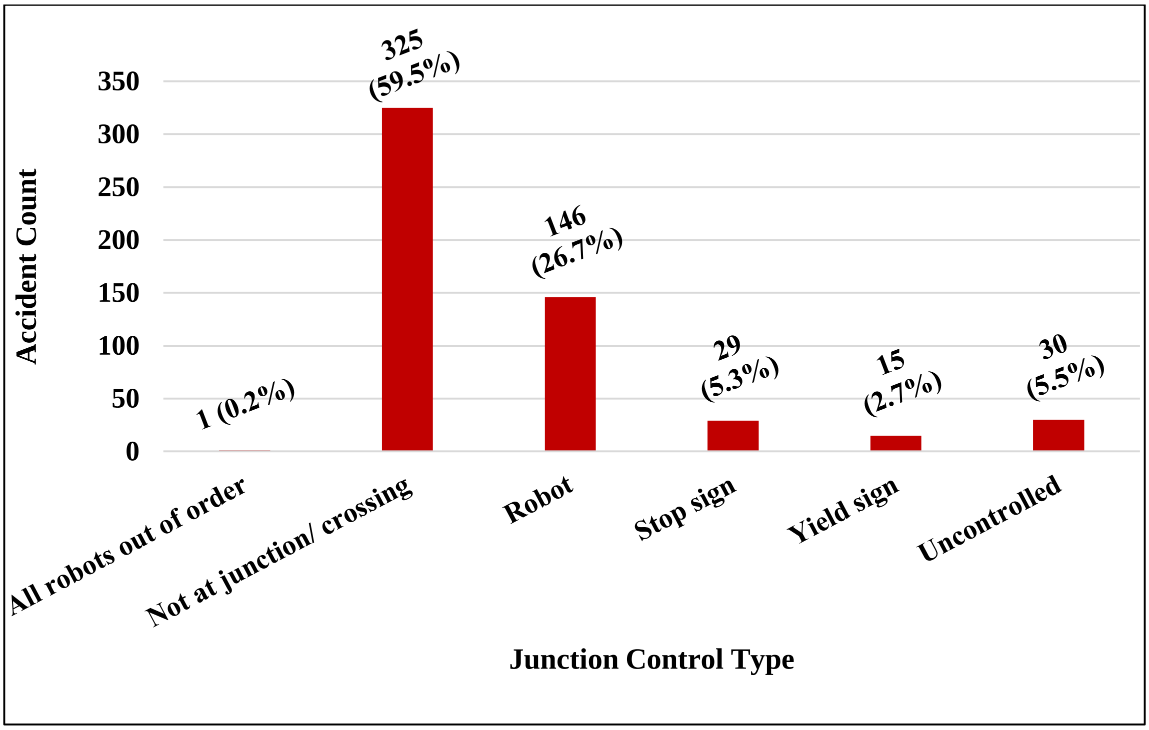

Figure 4.9b Fatal Accidents by Junction Control Type from 2011-2015.

4.2.10 Fatal Accidents by Type of Collision from 2011-2015

Figure 4.10 shows a disproportionate distribution of fatal accidents by type of collision from 2011- 2015. The largest proportion of fatal accidents was due to a vehicle-pedestrian collision (67.9%), followed by vehicle-fixed object collision (10.1%), rear-end collision (4.6%) and right angle straight collision (3.3%) (Figure 4.10). Results show that vehicle-pedestrian collisions are the leading causes of road deaths, probably because the vehicle driver did not notice the pedestrian on the road or the pedestrian entered the roadway where it was unsafe to so (Rankavat and Tiwari, 2016). These findings correlate with Durban City Engineers Unit (2001), who mentioned that 65% of all the road traffic collisions in the municipality were vehicle-pedestrian type. In a study done in Limpopo, Gainewe and Masangu (2010) concluded that the leading collision type from 2005 – 2009 was vehicle-pedestrian with more than 30% of fatal accidents attributed to jaywalking and lack of pedestrian facilities on the roads. Vehicle-pedestrian collisions represent a significant component of all road traffic fatalities worldwide (Olukoga, 2003). Hijar *et al.* (2001) reported that the percentage of deaths from vehicle-pedestrian collisions in Mexico is 57%, while WHO (2009b) reported that in Malawi this figure is 45% and in Mozambique 68%. The higher involvement of pedestrians in road traffic accidents may be attributable to an increased exposure arising from more people making walking trips (Olukoga, 2003; Osidele, 2016). The risk of a motor vehicle colliding with a pedestrian increases in proportion to the number of motor vehicles interacting with pedestrians (WHO, 2013b), and pedestrians typically misjudge high speed vehicles, causing a false sense of safety which often results in the pedestrian being struck (WHO, 2013b). Carole Miller Research (1998) highlights that drunken pedestrians contribute to vehicle-pedestrian collisions because they have impaired judgement, likely to have slower reaction time and lack the ability to assess the safeness of walking conditions.

With regards to vehicle-object collisions, which were the second largest collision type in the greater Durban City from 2011 – 2015, Adeoye *et al.* (2014) also reported that this type of collision was the most frequent on Nigerian roads accounting for 29% of 388 accidents and responsible for the highest casualty of 35% patients. Several studies attribute vehicle-object collisions to be among the most frequent in causing fatalities, for an example, Haworth *et al.* (1997) mentioned that 47.2% fatal accidents in Melbourne in 1996 occurred due to a vehicle colliding with a tree; Nilsson and Wenall (1998) stated that vehicle-pole collisions resulted in

10% of single vehicle fatalities in 1995 and 12% of those in 1995 in Sweden; Kloeden (1999) reported that 23% of fatal accidents in South Australia from 1985 – 1996 were due to a vehicle colliding with trees.

Rear-end collisions occur due to negligence, following too close, speeding, steep gradients, road works, faulty brakes and smooth tyres (Vogel and Bester, 2005). Rear end collisions were responsible for 4.6% of fatal accidents in the study area (Figure 4.10). In a similar study, Sullivan and Flannagan (2003) mentioned that rear-end collisions accounted for 30% of all accidents and only 5% of all fatal accidents in the United States of America in 2001, suggesting that while numerous, rear-end collisions are especially fatal. These findings are contrary to (Vogel and Bester, 2005), who reported that rear-end collisions accounted for 25.5% of fatal accidents recorded on the R44 in the Western Cape from 1999 – 2003. Although rear-end collisions contributed a small proportion of all fatal accidents in the greater Durban City from 2011 – 2015, they represent a significant national cost hence the need to develop effective countermeasures for this type of collision.

Right angle straight collisions occur due to reckless driving, failing to stop at intersections by disregarding red traffic signals, disregarding pedestrian red man signal or crossing, disregarding yield and stop signs, and faulty brakes (Vogel and Bester, 2005). In this study, right angle straight collisions accounted for 3.3% of fatal accidents. Other types of collision contributed to a much less occurrence of fatal accidents in the greater Durban City from 2011 – 2015. For an example, turn right opposing and sideswipe same direction collisions recorded 2.4% of fatal accidents, while single vehicle overturn resulted in 2.2% of the total fatal accidents from 2011 – 2015. Single vehicle overturns are a cause of concern, as they are likely to result in multi-vehicle collisions and an additional loss of lives (Hunter, 2006). In this study, multi-vehicle rear end collisions and right angle turn collisions both accounted for 1.3% of fatal accidents. According to Mathis (2011), multi-vehicle rear end collisions are a global problem as they happen more frequently but not most deadly. Overall, a similar pattern and trend of fatal accidents by type of collision was observed in the annual analysis as presented in Appendices 4.10a – 4.10e. These statistics indicate that measures to reduce vehicle-pedestrian collisions must be given priority.

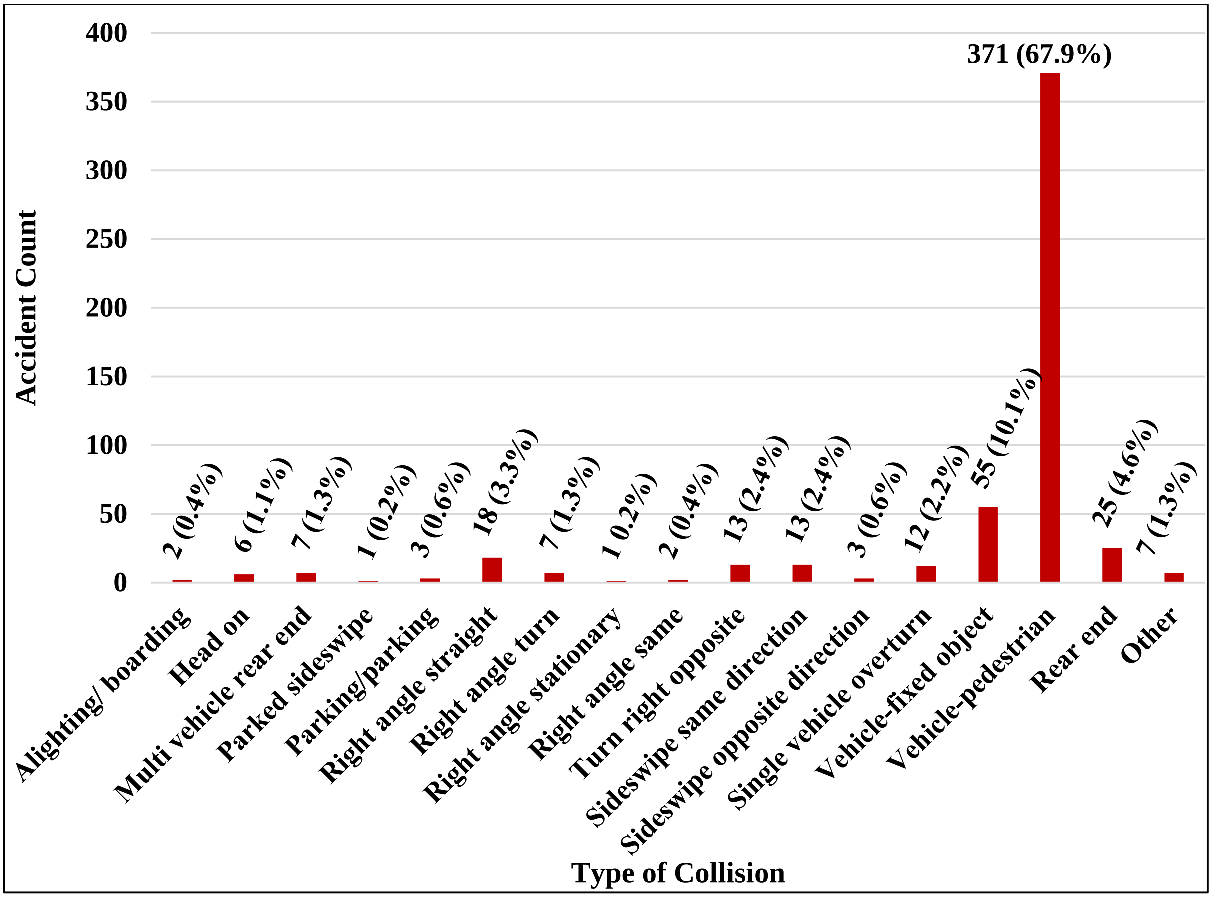

Figure 4.10 Fatal Accidents by Type of Collision from 2011-2015.

4.2.11 Causative Factors of Fatal Accidents from 2011-2015

The causes of road fatal accidents broadly categorised as human factors, vehicle characteristics and road-environment factors, and their risk factors were examined. The results revealed that out of the 546 fatal accidents recorded in the greater Durban City from 2011 – 2015, human factors are the leading causes, accounting for 92.5%, whereas vehicle characteristics were responsible for 2%, road - environment factors resulted in 0.2% and unknown factors accounted for 4.9% (Figure 4.11). These findings partially corroborate findings by the RTMC (2009), who reported that human factors (82.9%) are the predominant causative factors in road traffic accidents in South Africa compared with vehicle characteristics (9.13%) and road-environment factors (8.02%). Also, findings of this study agree with Odero *et al.* (2003); Odero (2004); Molla *et al.* (2014) in their studies on road traffic causative factors. For an example, Odero (2004), mentioned that human factors accounted for 70% of all causes on road traffic accidents in Kenya. Other research has shown that in several countries, human factors are responsible for more than 90% of traffic accidents and only a small proportion of accidents can be attributed to vehicle characteristics and road-environment factors (World Bank, 1997). However, in-depth analysis has revealed that accidents are not caused by a single factor but by a combination of factors (Zein and Navin, 2003); (Peden *et al.* 2004). The risk factors in each category of causative factors is presented below.

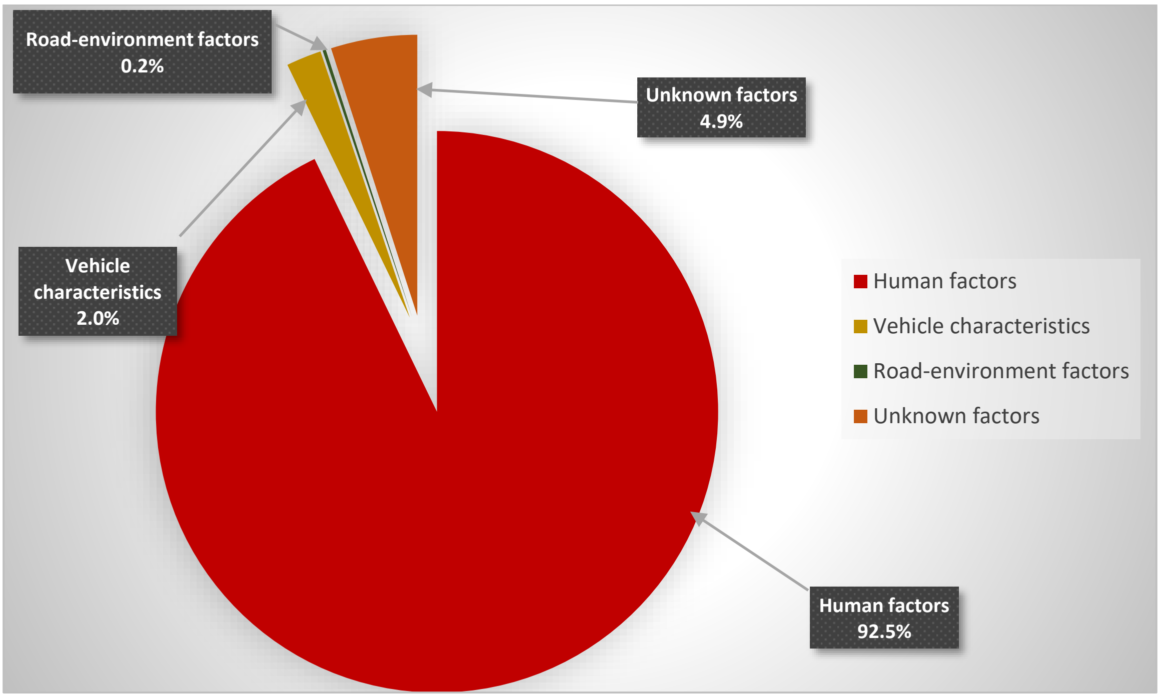

Figure 4.11 Causative Factors of Fatal Accidents from 2011-2015.

4.2.11.1 Human Factors

Out of the 92.5% of road traffic fatal accidents recorded in the greater Durban City from 2011 – 2015, several high risk behaviours were identified. These include; pedestrians entering the roadway when unsafe to do so (44.1%), driver losing control of the vehicle/ skidding (12.1%), failure of the driver to notice pedestrians or another vehicle (6.0%), disregarding red traffic signal (4.6%), speeding (4.2%) and jaywalking (4.2%) (Table 4.2). Results show that pedestrians are the most vulnerable road users and that measures to reduce the pedestrian involvement in fatal accidents must be given priority (Chiduo and Minja, 2001). These findings are consistent with reports by the RTMC (2011), which stated that the percentage of pedestrian accidents to total accidents is approximately 33%, far greater than the world average of 22%, this illustrates the South African pedestrian safety problem (Rosén and Sander, 2009; Rosén *et al.* 2011; WHO, 2013a). Several studies reported unsafe pedestrian behaviour, including jay walking, as a major factor in pedestrian injuries and fatalities. In a study done in Florida, it was reported that pedestrians were at fault in 80% of all accidents and 53% of these occurred as a result of pedestrians crossing a roadway where it was unsafe to do so (Lee and Adbel-Aty, 2005). In a similar study, unsafe pedestrian behaviour accounted for 90% of accidents in the United Kingdom (Teanby, 1993).

According to Suffla and Niekerk (2004); Lagarde (2007), the largest group of pedestrians involved in road traffic accidents are those who live in informal settlements, often in close proximity to highway roads. In South Africa, the influx of rural-urban migration has led to the establishment of various informal settlements adjacent to or close to road networks in order to gain easy access transport (Riyad and Myeza, 2002). However, these locations are characterised by the lack of pedestrian sidewalks, inconsistent use of pedestrian bridges, pedestrian crossings and traffic lights (Riyad and Myeza, 2002). In a similar study along a 22km stretch of the Golden Highway P73/1, De Beer (2002) mentioned that the densely-populated areas on either side of the Golden Highway generated large volumes of pedestrians throughout the day, crossing and walking alongside the road. In this study, jay walking (4.0%) significantly contributed to the total accidents recorded in the study period (Table 4.2). The risk of pedestrians being involved in an accident increases along such locations because the proportion to the number of vehicles interacting with pedestrians is high (WHO, 2013). Therefore, pedestrians must be aware of the potential danger whenever they take to the roads and must follow safety regulations in order to reduce their involvement in fatal accidents (RTMC, 2011).

Negligent driving such as losing control of the vehicle/ skidding (12.1%) also contribute significantly to road traffic fatal accidents in the greater Durban City, this correlates to Clarke *et al.* (2007) who reported that 44% of the fatal accidents sampled in London involved a vehicle going out of control on a bend or curve. Losing vehicle control is largely associated with speeding (Muviringi, 2012), therefore motor vehicle drivers should adhere to the speed limits and drive accordingly under harsh weather conditions to avoid colliding with other vehicles, pedestrians or other objects which could result in a fatal accident.

Another human factor identified to contribute to road traffic fatal accidents in the study area is failure of the driver to notice pedestrians or another vehicle (6.0%). Speeding and distracted driving such as the use of handheld phones, adjusting mirrors, reading billboards and non-wearing of reflective clothing at night by pedestrians, influence the driver not to notice the pedestrians or other vehicles which results in a fatal collision (WHO, 2013a). In Nigeria driving etiquette was reported as the single most important contributing factor to RTAs, as driver factors contributed approximately 57% of road traffic accidents and 93% of these were either entirely due to driver actions or due to driver actions in combination with other factors (Agbonkhese *et al*. 2013). A report by WHO (2013a) states that reckless and negligent driving are among the leading causes of road traffic injuries and deaths in Africa. In a similar study, Li (2006) mentioned that in Texas, most road accidents occurred due to impatient and wrongful driving by motorists. In India, Bhat (2016), mentioned that reckless driving such as changing lanes too quickly, making improper turns and passing red traffic lights were among the causes of road deaths.

Speeding resulted in 4.2% of fatal accidents in the greater Durban City from 2011 – 2015 (Table 4.2). Several studies reveal that there is clear evidence of the effect of speed on accident rates and severity. Afukaar (2003) identified speed as the main contributory factor in 50% of road crashes in Ghana between 1998 and 2000; Odero *et al.* (2003) mentioned that speeding and other driving errors such as loss of control of vehicle, misjudgement and improper overtaking, contributed to 44% of all police-reported road traffic accidents in Kenya; Wang, *et al.* (2003) showed that excessive speed was the main reported cause of road traffic crashes in China, and Bhat (2016) mentioned that around one-third of road accidents in India are caused by over speeding.

The effect on crash risk comes mainly via the relationship between speed and stopping distance. The higher the speed of a vehicle, the shorter the time a driver has to stop and avoid a crash, including hitting a pedestrian. Taking into account the time needed for the driver to react to an emergency and apply the brakes, a car travelling at 40 km/hr will stop in 27 metres (WHO, 2013b). In addition, Lay (1986) asserts that an impact speed of more than 130km/hr involves more than twice the energy of one at 90km/hr, because driving at high speeds makes the vehicle less stable, the driver and other road users have less time to react to the situation and that the severity of the accidents increases. Factors cited as influencing the choice of speed are the driver (age, gender, driving attitude, alcohol level and number of people in the vehicle), the design of the road (quality of surface, width and layout), the vehicle (type, comfort and maximum speed limit), the traffic (volume, composition and prevailing speed), the environment (weather, light and enforcement) as some of the factors that influence the drivers speed choice (Peden *et al*. 2004). For an example, Steunenberg and Sinclair (2014) posit that most drivers believe that exceeding the speed limit will significantly decrease the journey time, and that the advancement in car technology of producing faster vehicles encourages motorists to over speed which often leads to road traffic fatal accidents (ROSPA, 2017). In an effort to reduce speed related fatal accidents, The Department of Transport regulated speed limits to be reduced from 60km/hr to 40km/hr in urban areas, from 100km/hr to 80km/hr in rural areas and from 120km/hr to 100km/hr on freeways running through a residential area with effect from May 2017 (BusinessTech, 2017). However, the challenge with these speed regulations is that many drivers do not adhere to this change in speed limit, with the resultant increase in safety for pedestrians (Mokoma, 2017).

Alcohol and narcotics related accidents also have a well-documented evidence. According to the World Report on Road Traffic Injury Prevention and other studies, drinking and driving increases both the risk of an accident and the likelihood of death or serious injury resulting from the accident (Hingson and Winter, 2003; Peden, *et al.* 2004; Bergen *et al.* 2011). A Global Status report by the WHO (2015) mentioned that South Africa has the highest prevalence of road deaths associated with alcohol abuse. Clarke *et al.* (2007), mentioned that 24% of fatal accidents in London were caused by driving over the drink-drive limit and intoxication from drugs such as cannabis, cocaine and heroin. The study in the greater Durban City revealed however that alcohol intoxicated drivers and pedestrians resulted in 1.3% of fatal accidents, which is a low proportion over the period of five years (Table 4.2). This finding correlates to Kyei and Masangu (2012), who mentioned that in Limpopo, alcohol intoxication by drivers and pedestrians contributed to 3.6% of fatal accidents compared to other human factors. This can be explained by the law enforcement interventions on alcohol consumption such as random blood alcohol concentration (BAC) breathalyser checks by police, and behavioral change by drivers and pedestrians.

The study further shows that other human factors such as driving into rear of front vehicle, disregarding pedestrian red man signal, driver taking evasive action for another vehicle, driver entering roadway when unsafe to do so, and turn in face of oncoming traffic, among others jointly contribute to a significant 10.8% of the total fatal accidents recorded (Table 4.2%).

4.2.11.2 Vehicle Characteristics

The condition of the vehicle on the road may determine whether an accident would occur given the presence of other contributing factors (Chiduo and Minja, 2001). Vehicle characteristics accounted for 2% of the total fatal accidents within the greater Durban City from 2011 - 2015. Of these, brake failure (5) were the leading cause of road traffic fatal accidents, followed by other mechanical defects (3), and tyre bursts, loss of wheel and suspension failure which jointly contributed 3 fatal accidents. These findings corroborate van Schoor *et al*. (2001), who reported that defective tyres and brake failure contributed to 3% of the accidents resulting from mechanical failures. Furthermore, Vanderschuren and Irven (2002) indicated that The Arrive Alive surveys have shown that 17% of fatal road accidents in South Africa are caused by vehicle characteristics, mostly due to poor tyres and braking systems. Kyei and Masangu (2012) mentioned that tyre bursts and brake failure were the leading contributory vehicle characteristics to fatal accidents in the Limpopo province accounting for 56.9% and 17.9% respectively.

4.2.11.3 Road-Environment Factors

According to Chudo and Minja (2001), road faults are rarely listed on accident reports. Similarly, Moodley and Allopi (2008) assert that it is misleading to assume that the information on the recorded Accident Report form constitutes proper investigation that may be used to reconstruct an accident, because the police or traffic officer at the accident scene does not investigate the accident but merely records accident information on the Accident Report form. Lack of proper investigations and report format aid the uncertainty in the actual contribution of road-environment accidents in South Africa (Moodley and Allopi, 2008). In line with the statements above, only 0.2% of all fatal accidents recorded in the greater Durban City from 2011 – 2015 occurred due to road-environment factors, specifically an object thrown or which fell into a vehicle (Figure 4.11 and Table 4.2). The primary data lacked factors related to road geometry or shape, among other which could aid in-depth analysis on the contribution of road-environment factors to fatal accidents. Nevertheless, the following sections, although not categorised as causes of accidents per se in the primary data, provide information on the road-environment factors' influence on the occurrence of fatal accidents: Section 4.2.2 on fatal accidents by time, Section 4.2.3 on fatal accidents by lighting conditions, Section 4.2.6 on fatal accidents by weather conditions, Section 4.2.7 on fatal accidents by road type, Section 4.2.8 on fatal accidents by road surface type and description and Section 4.2.9 on fatal accidents by junction control and junction control type.

4.2.11.4 Unknown Factors

Table 4.2 shows that 4.9% of road traffic fatal accidents occurred due to unknown causes or there were no witnesses to describe the accident event. At this point, one may take another perspective on traffic accident fatality causes, which is cultural superstitions or myths. In an attempt to understand the role of cultural superstitions or perceptions on causing road traffic accidents, Peltzer and Renner (2003) conducted a study on South African black taxi drivers, whose findings revealed that accidents could be avoided by using protective medicines, consulting traditional healers or prophets and by undergoing cleansing ceremonies. A similar research by Okyere (2006) in Ghana found that some Ghanaians associate road accidents to superstitions, witchcraft and evil forces so that witches and evil forces would obtain more blood for their spiritual activities. Muviringi (2012) asserts that it is vital to consider the view of accidents as random, due to bad luck, witchcraft or God. Cultural perceptions on the causes of traffic accidents may have a strong influence on the methods that governments can employ to prevent accidents.

Table 4.2 Causative Factors and Number of Fatal Accidents from 2011-2015

Causative Factors of Fatal Accidents	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
Alcohol/ narcotics (driving under influence)	2	1			3	6
Alcohol/ narcotics (pedestrian under influence)	1					1
Changing lanes dangerously	1	1		2	1	5
Disregarding pedestrian red man signal	2	1	1	2	3	9
Disregarding red traffic signal	4	4	5	6	6	25
Disregarding road traffic sign –stop sign				1	1	2
Driver distracted	1					1
Driver did not see pedestrian/ vehicle	13	6	5	7	2	33
Driver medical emergency		1		1	1	3
Driver taking evasive action for object/ animal	1					1
Driver taking evasive action for another vehicle	1	6			1	8
Driver taking evasive action for pedestrian		1		1	1	3
Entering roadway when unsafe to do so (driver)	1	3	1	2	1	8
Entering roadway when unsafe to do so (pedestrian)	67	55	35	36	48	241
Following too close	2	2			1	5
Jaw walking	4	3	5	5	5	22
Losing control/ skidding	12	19	17	5	13	66
No witness-cause unknown	4	5	1	9	8	27
Other mechanical defect		1	1		1	3
Overtaking		2			1	3
Passenger falling whilst vehicle in motion		1		1	1	3
Passenger injured in public motor vehicle					1	1
Pedestrian visibility/ obscured					1	1
Playing/ fighting on roadway	1	2		2	1	6
Speeding	5	4	1	9	4	23
Turn in face of oncoming traffic	1	3		2	1	7
Reversing when unsafe to do so	2					2
Rolling backward from stationary position	1			1		2
Driving into rear of front vehicle	3	3		3	2	11
Brake failure		3	1	1		5
Loss of wheel			1			1
Corner cutting whilst turning		1				1
Corner taking too wide		1				1
Disregarding road marking- channelising lines		1				1
Driver failed to keep left on roadway	1	1				2
Object thrown/ fell into vehicle	1	1				2
Passenger falling whilst alighting/ boarding	1					1
Suspension/ axle failure	1					1
Tyre blown out	1					1
Disregarding pedestrian crossing		1				1
Disregarding road traffic sign no U-turn sign			1			1
Total	**134**	**133**	**75**	**96**	**108**	**546**

4.3 Conclusion

This Chapter has examined the patterns and trends of road traffic fatalities in the greater Durban City from 2011 - 2015. It was observed that 2011, a year which marked the beginning of the UN Decade of Action for Road Safety had the highest fatal accidents. However, fatal accidents declined by 59 from 2011-2013, with 2013 recording the lowest fatal accidents. Fatal accidents increased by 33 from 2013 – 2015. Majority of fatal accidents occurred on weekends (52.4%) and the highest record of fatal accidents were recorded in March, May, June and December jointly contributing to 39.2% of the total recorded. Furthermore, the 18:00-23:59 time block (33.3%) recorded the highest number of fatal accidents. The study also found that there is no significant difference between daylight and night-time fatal accidents as they contributed to 45.1% and 44.1%, respectively. 91.1% of fatal accidents were recorded in clear weather, 93.0% on dry road surfaces and 99.6% on tarmac roads. Dual carriageways (30.4%) were responsible for the highest fatal accidents record from 2011 – 2015, followed by freeways (26.7%) and single carriageways (25.8%). However, single carriageways (34.3%) were the leading cause of fatal accidents in 2015 alone. The largest (60.8%) proportion of fatal accidents occurred on portions of the road other than a junction. Of all collision types recoded, the leading collision type was vehicle-pedestrian which resulted in 67.9% of fatal accidents from 2011 – 2015.

This study has found that there is significant difference in contributory factors of road fatal accidents under human factors, vehicle characteristics and road and environmental factors. Human factors (92.5%) account for the highest proportion of all fatal accidents recorded from 2011 – 2015, followed by unknown factors (4.9%), vehicle characteristics (2%) and road-environment factors contributing 0.2%. Pedestrians are the single most vulnerable road user in the greater Durban City because of entering the roadway when unsafe to do so, which contributed to 44.1% of the total fatal accidents recorded from 2011 – 2015. Brake failure (0.9%) and other mechanical defects (0.5%) were among the leading contributors to vehicle characteristics related fatal accidents. The next chapter examines the hotspot locations for fatal accidents in the greater Durban City from 2011-2015.

CHAPTER FIVE

ROAD TRAFFIC FATAL ACCIDENTS HOTSPOTS WITHIN THE GREATER DURBAN CITY FROM 2011-2015

5.1 Introduction

Identifying fatal accident clusters within the greater Durban City using GIS-aided technique can highlight contributory factors that can assist the government and its agencies to implement corrective measures to make driving safe at such spots and improve these roads. The road traffic fatalities hotspots within the greater Durban City were identified based on the location and attributes where the road accident occurred with the aid of Kernel Density Estimation (KDE) analysis and Getis-Ord Gi* hotspot analysis. There were different levels of densities from Kernel density analysis and levels of confidence derived from Getis-Ord Gi* hotspots analysis based on the data for each year. The different maps generated from the Kernel density analysis and Getis-Ord Gi* hotspots analysis are presented below for each year from 2011 - 2015. Some hotspot locations appeared consistently throughout the study period in the study area. Prior to performing KDE and Getis-Ord Gi* hotspot analysis, the data was examined for spatial autocorrelation using global Moran's I and Anselin Local Moran's I (See Chapter 2, Section 2.6; Chapter 3, Section 3.5.2 and Section 3.5.3) to check for spatial clustering within the data as it is a requisite for hotspot analysis (Satria and castro, 2016). The integrate, collect events and calculate distance functions, were used to aggregate and find an appropriate search radius distance for executing Incremental Spatial Autocorrelation (ISA) as discussed in Chapter 3, Section 3.5.1, to get the peak distance for Moran's I, Anselin Local Moran's I, Getis-Ord Gi* hotspot analysis and Kernel density analysis.

5.2 Distribution of Road Traffic Fatal Accident Hotspots in 2011

Road traffic fatal accidents data was subjected to the integrate, collect events, calculate distance functions and ISA to get an appropriate search radius for running further analysis. The results retained were a minimum distance of 15.41m, an average distance of 401.29m and a maximum distance of 1248.74m. The maximum (1248.74m) and average (401.29m) distances were explored in ISA to determine the first peak at which clustering occurs in the data so it can be used for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi*. The ISA tool identified one peak value at a distance of 2051.31m. Global Moran's I retained a z-score of -

0.08 and a p-value of 0.14, entailing that the pattern of fatal accidents distribution in the greater Durban City in 2011 does not appear to be significantly different than random, as these values fall within the yellow-middle region of the graph, with a z-score range of -1.65 to +1.65 (see Chapter 3, Section 3.5.2, Figure 3.2). Therefore, the null hypothesis which states that features values are randomly distributed across the study area is accepted at a 90% confidence interval (Prasannakumar *et al*. 2011).

While global Moran's I quantifies the spatial autocorrelation as a whole, the local indicators of spatial association (LISA) measure the degree of spatial autocorrelation of fatal accidents at each specific location (Anselin, 1995) by using Anselin local Moran's I (see Chapter 3, Section 3.5.3). It is also good for identifying and examining local spatial cluster patterns and spatial outliers (Fu *et al*. 2014; Erdogan *et al*. 2015). Figure 5.1 shows the distribution of local spatial clusters and outliers of road traffic fatal accidents in 2011. Results show that there were two locations categorised as high clusters and one location categorised as a low outlier surrounded by high values (as discussed in Section 3.5.3), namely, N2 Freeway/ Sherwood (z-score = 7.26; p-value = 0), N2 Freeway/ Westwood Mall (z-score = 8.19; p-value = 0) and Canongate Road/ Julius Nyerere Avenue/ David Webster Street (z-score = -1.43; p-value = 0.15). Canongate Road/ Julius Nyerere Avenue/ David Webster Street is considered a statistically significant spatial data high outlier with surrounding low values (see Chapter 3, Section 3.5.3; and Figure 5.1), although these values fall within the random segment as displayed in Chapter 3, Section 3.5.2.

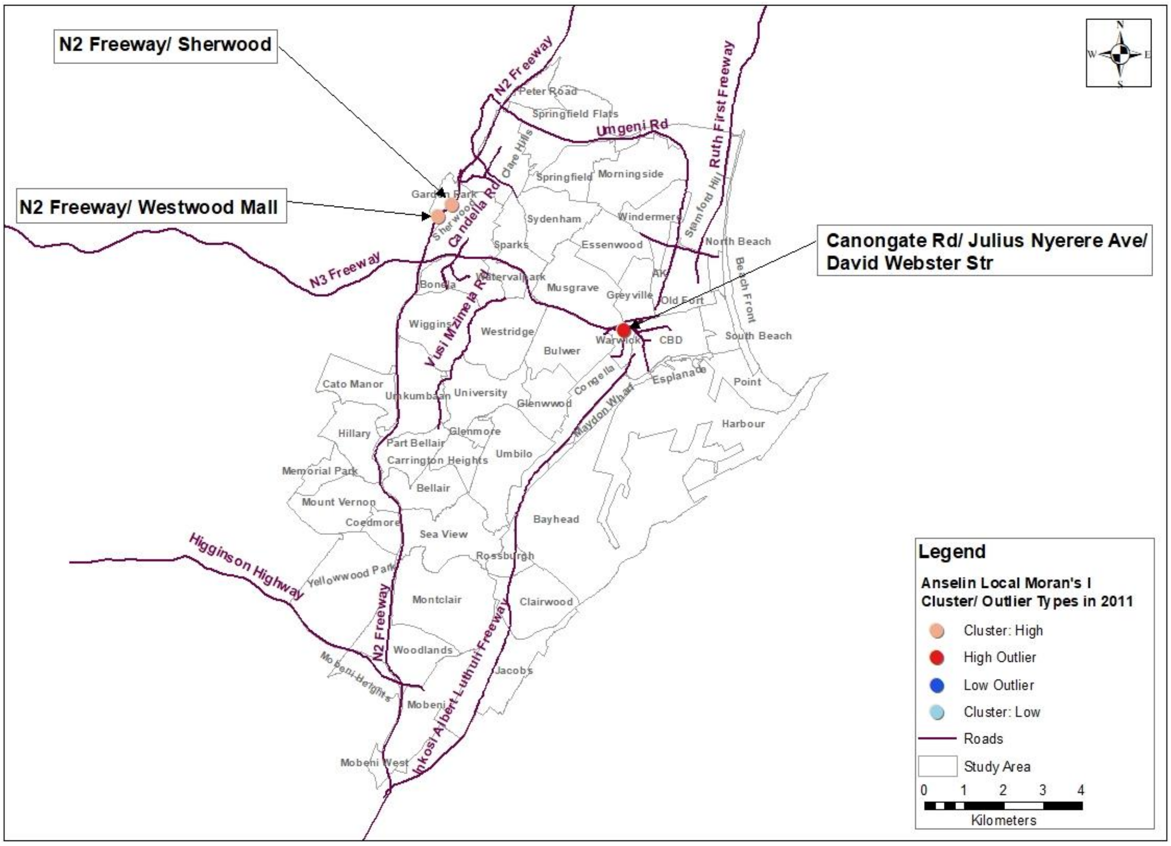

Figure 5.1 Anselin Local Moran's I of Fatal Accidents in 2011 (Data source: UKZN School of AEES and Durban City Engineers Unit).

The next step after identifying spatial clustering of road traffic fatal accidents in 2011 was to conduct Kernel Density Estimation (KDE) and Getis-Ord Gi* hotspot analysis to determine the spatial extent of these clusters. The KDE results in Figure 5.2 shows the locations where fatal accidents are clustered based on the Epanechnikov kernel, at an inverse distance and a categorisation of inherent data by natural breaks based on the Jenks algorithm (see Chapter 2, Section 2.6; Chapter 3, Section 3.5.4). Out of 134 fatal accidents recorded in 2011, AK, CBD, Bulwer, Congella, Esplanade, Greyville, Maydon Wharf, Musgrave, Old Fort and Warwick were identified as areas with high fatal accident clusters, with Kernel density values ranging from 3.39 – 5.13 (Figure 5.2 and its legend).

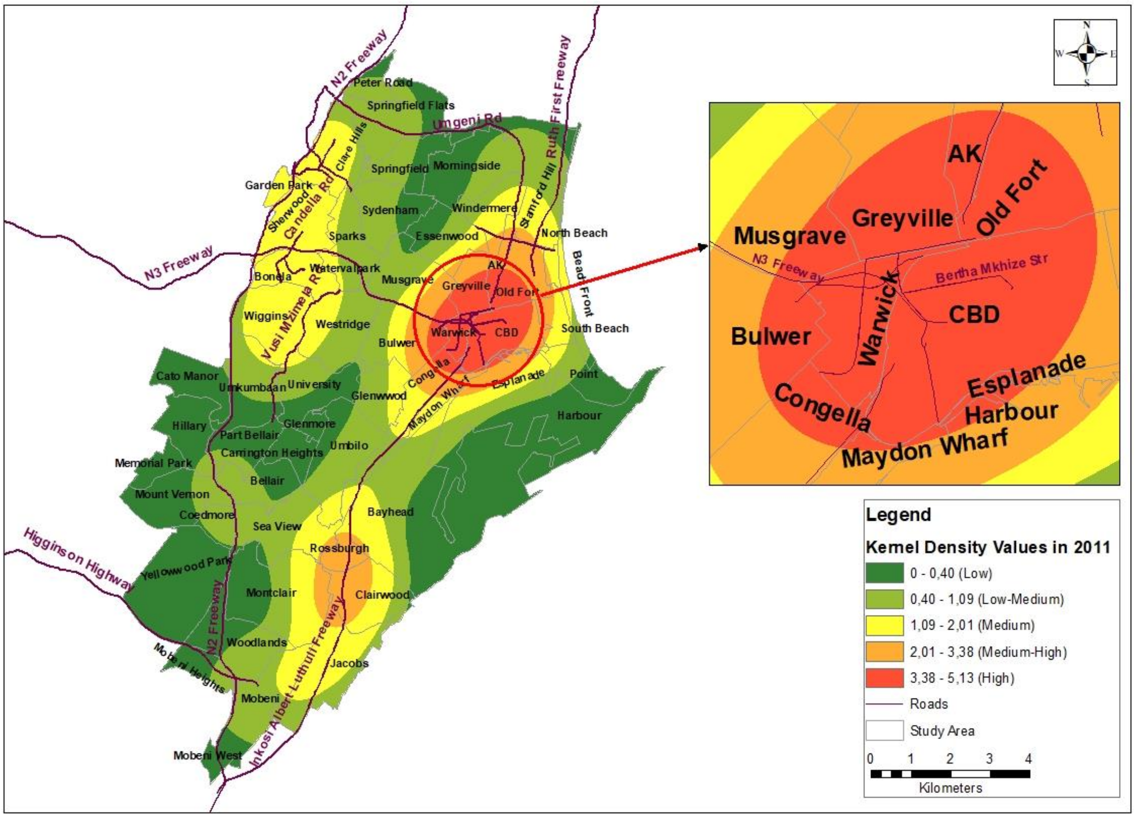

Figure 5.2 Kernel Density Estimation of Fatal Accidents in 2011 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Figure 5.3 shows hotspot locations for fatal accidents in 2011 based from Getis-Ord Gi* hotspot analysis. Out of 134 fatal accidents recorded in 2011, 8 accidents occurring on 3 locations at a 99% confidence interval were identified as statistically hotspots (see Chapter 2, section 2.6 and Chapter 3, Section 3.5.5) with a z-score ranging from 4.25 – 6.51 and p-values ranging from 0-0.000021. The areas in which the hotspots for fatal accidents occurred in 2011 were Palmiet, Sherwood and Warwick South, with the specific road locations being:

1. N2 Freeway/ at off ramp to Umgeni Road (Northbound); Palmiet (1 accident)

2. N2 Freeway/ Westwood Mall overhead bridge to King Cetshwayo Highway; Sherwood (3 accidents)

3. Canongate Road/ Julius Nyerere Avenue/ David Webster Street; Warwick-South (4 accidents)

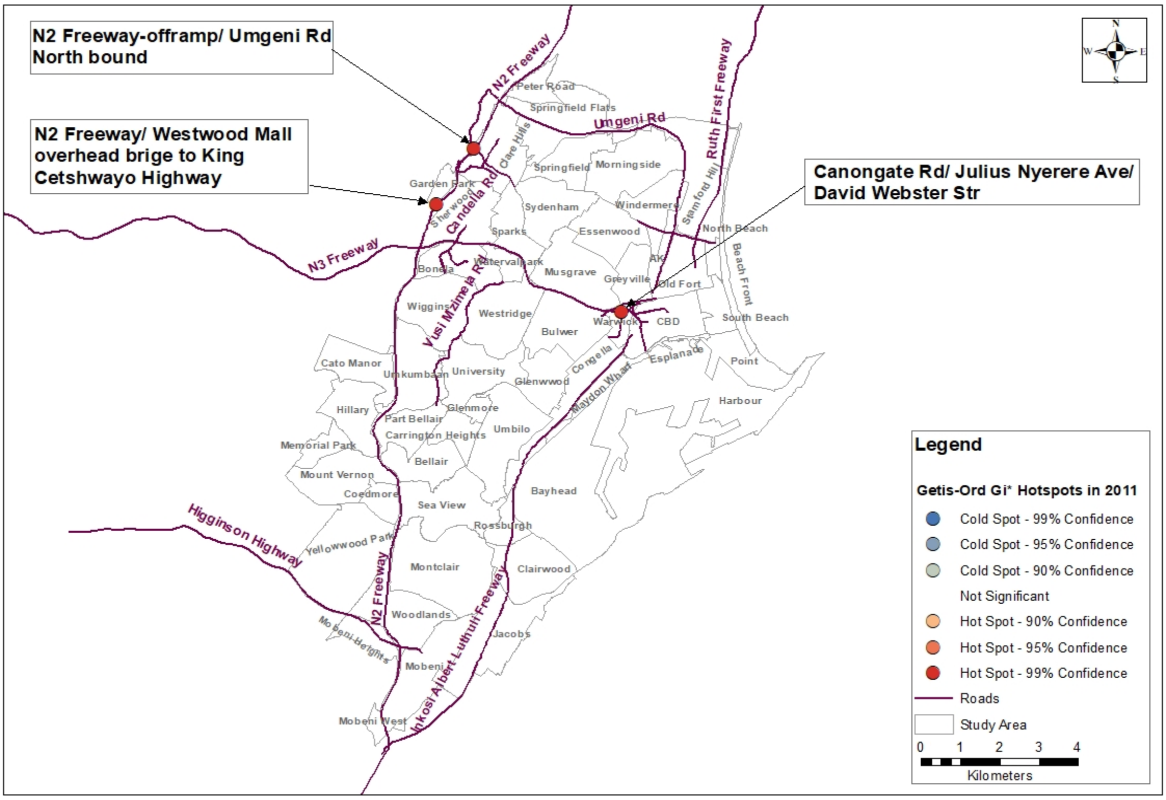

Figure 5.3 Getis-Ord Gi* Hotspot Analysis of Fatal Accidents in 2011 (Data source: UKZN School of AEES and Durban City Engineers unit).

These hotspots occurred in areas of busy roads with heavy traffic flow (Mokoma, 2017), most of which are commercial hubs and in close proximity to informal settlements. Each accident resulted in one fatality, implying that 8 lives were lost on these hotspot locations in 2011. Freeways recorded 4 fatal accidents, followed by one way roads (3) and dual carriageway (1). These types of roads host large traffic volumes resulting in a high risk of fatal accident occurrence (ROSPA, 2017). Weekends and weekdays recorded an equal number of fatal accidents (4 per category), although Monday alone had the highest occurrence of three fatal accidents, a finding which is contrary to the norm weekends are responsible for the highest occurrence of fatal accidents (Ukoji, 2014). The months in which the fatal accidents occurred were May (3), July (2), February, April and September, jointly contributing to 3 of the total fatal accidents recorded on those hotspots. Night time fatal accidents at these hotspot locations were 6, while daylight and dawn/-dusk recorded an accident each. Nighttime fatal accidents are high due to an increase in human error attributable to fatigue, driving under the influence of alcohol or narcotics and speeding (Sebogo *et al*. 2014). All the hotspot locations determined by Getis-Ord Gi* hotspot analysis resulted from three collision types namely, vehicle-pedestrian accounting for 6 accidents, sideswipe same direction and rear-end collisions jointly accounting for 2 accidents. Vehicle-pedestrian collisions represent a significant contribution to fatal accidents, mainly due to pedestrians entering the roadway when unsafe to do so (Gainewe and Masangu, 2010). The causes of fatal accidents at the identified hotspot locations were, pedestrians entering the roadway when unsafe to do so (4 of 8), speeding, pedestrian walking under the influence of alcohol, changing lanes dangerously and the driver not noticing a pedestrian/ vehicle, jointly contributing 4 accidents and fatalities.

Further analysis of Figures 5.2 and 5.3 reveal that Getis-Ord Gi* results (Figure 5.3) identified few clusters of hotspots compared to KDE analysis (Figure 5.2) because Getis-Ord Gi* applies the concept of statistical significance of local clusters and determine the spatial extent of these clusters, rather than just clustering according to count as done by KDE (Gets and Ord, 1992).

Standard deviational ellipse (SDE) has long served as a versatile GIS tool for delineating the geographic distribution trend of features by summarising their dispersion and orientation around the mean centre (Wang *et al.* 2015). The ellipse can be created with one, two or three standard deviations, and using Euclidean or Manhattan distances (ESRI, 2016). A one SDE using Euclidean distance was created with the directional distribution tool in ArcGIS version 10.4 to illustrate the directional trend of road traffic fatal accidents in 2011. Figure 5.4 shows that road traffic fatal accidents in 2011 were oriented in a Northeasterly-Southwesterly trend with a rotation of 19.01. The directional distribution of fatal accidents in 2011 was roughly elongated, thinner at the Northeasterly-Southwesterly apex and stretch laterally. This can be attributable to the low intensity of fatal accidents towards the top and bottom apex while increase at the central-lateral locations such as the Warwick junction, where high clusters of accidents occurred.

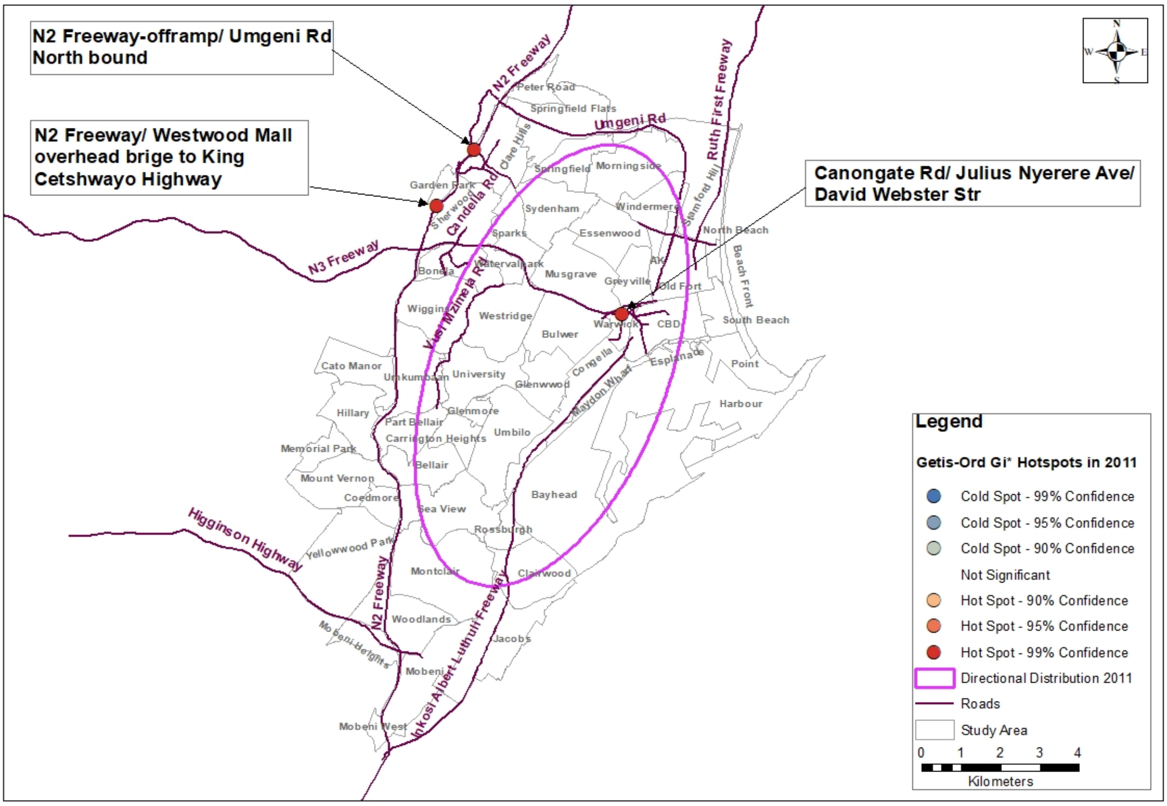

Figure 5.4 Directional Distribution (SDE) of Fatal Accidents in 2011 (See Purple ellipse)

(Data source: UKZN School of AEES and Durban City Engineers Unit).

5.3 Distribution of Road Traffic Fatal Accident Hotspots in 2012

The integrate, collect events and calculate distance tools were run, results retained were a minimum distance of 57.89m, average distance of 465.50m and a maximum distance of 1331.17m. The maximum and average distances were explored in ISA to determine the first peak at which clustering occurs in the data so it can be used for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi*. The ISA tool identified one statistically peak value at a distance of 3658.68m which was used to run the global Moran's I, Local Moran's I, KDE and Getis-Ord Gi* hotspot analysis. While deriving the Moran's I index, it was noted that there is a 99% confidence level that this clustered pattern is not a result of chance, given a z-score of 4.75 and a p-value of 0.000002 (See Chapter 3, Section 3.5.2, Figure 3.2). According to ESRI (2016) and Chapter 3, Section 3.5.2, a high z-score, together with a very small p-value means that the observed spatial pattern is very unlikely to be a result of random processes, so the null hypothesis can be rejected because these values fall in the far right tail of the normal distribution diagram in Figure 3.2.

Although global Moran's I indicated a clustered pattern of fatal accidents in 2012, it does not does show the specific location of clusters and outliers, hence the Local Indicators of Spatial Association (LISA) using Anselin Local Moran's I (see Chapter 3, Section 3.5.3) was used to identify the specific clusters and outliers. Figure 5.5 clearly shows 7 clusters of fatal accidents surrounded by high values, with z-scores ranging from 3.74 – 20.42 and p-values ranging between 0-0.00019 at a 99% confidence level. A positive I value indicates that the feature is surrounded by features with similar values (Anselin, 1995).The clusters occurred at the following roads: N2 Freeway/ overhead bridge to Clare Estate, N2 Freeway/ Shacks (Clare Estate vicinity), N2 Freeway/ Westwood Mall, N2 Freeway/ Spaghetti Junction Road, N3 Freeway/ Candella Road overhead bridge, N3 Freeway/ Bonela, and Kennedy Road/ Clare Road/ Goldman Road. Clustering of fatal accidents in those areas can be attributed to jaywalking from pedestrians at informal settlements which are located adjacent or close to the highways, which host a high traffic volume travelling at high speeds (Mokoma, 2017). The location of informal settlements close to these roads is a major risk to pedestrians who walk along or cross the roads at undesignated crossing points. Furthermore, it is likely that pedestrians are more at risk of being involved in a fatal accident due to lack of reflective clothing at night (Muviringi, 2012).

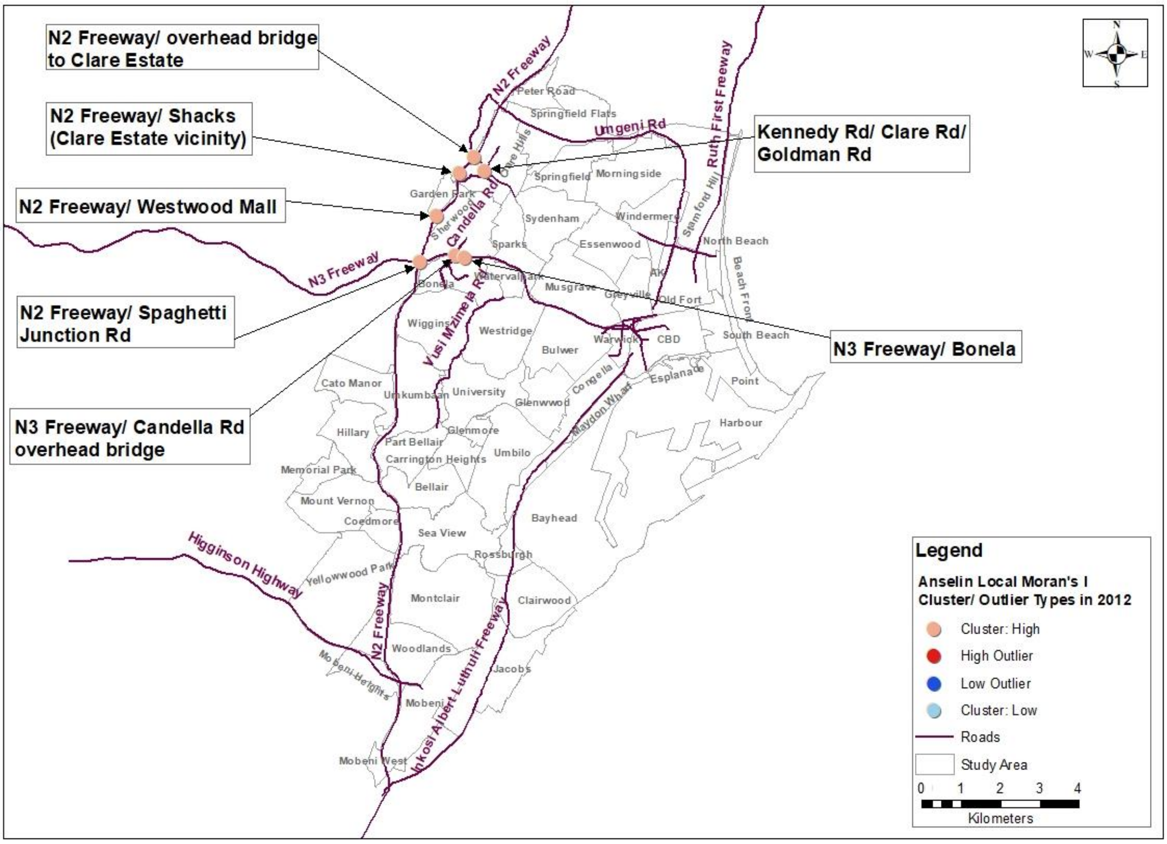

Figure 5.5 Anselin Local Moran's I of Fatal Accidents in 2012 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Having checked for clustering of fatal accidents as discussed in Chapter 3, Section 3.5.2 and 3.5.3, hotspot analysis using KDE and Getis-Ord Gi* was conducted. Figure 5.6 and its legend shows the distribution of fatal accidents hotspots in 2012 based on KDE. The following areas, with Kernel density values of 1.42 – 1.88, were identified as hotspots; A.K, Bonela, Bulwer, CBD, Clare Hills, Congella, Garden park, Musgrave, Sherwood, Sparks Warwick, Watervalpark, Westridge and Wiggins. These hotspot locations are comparably higher than in 2011 due to an increased clustering of fatal accidents along the N3 Freeway.

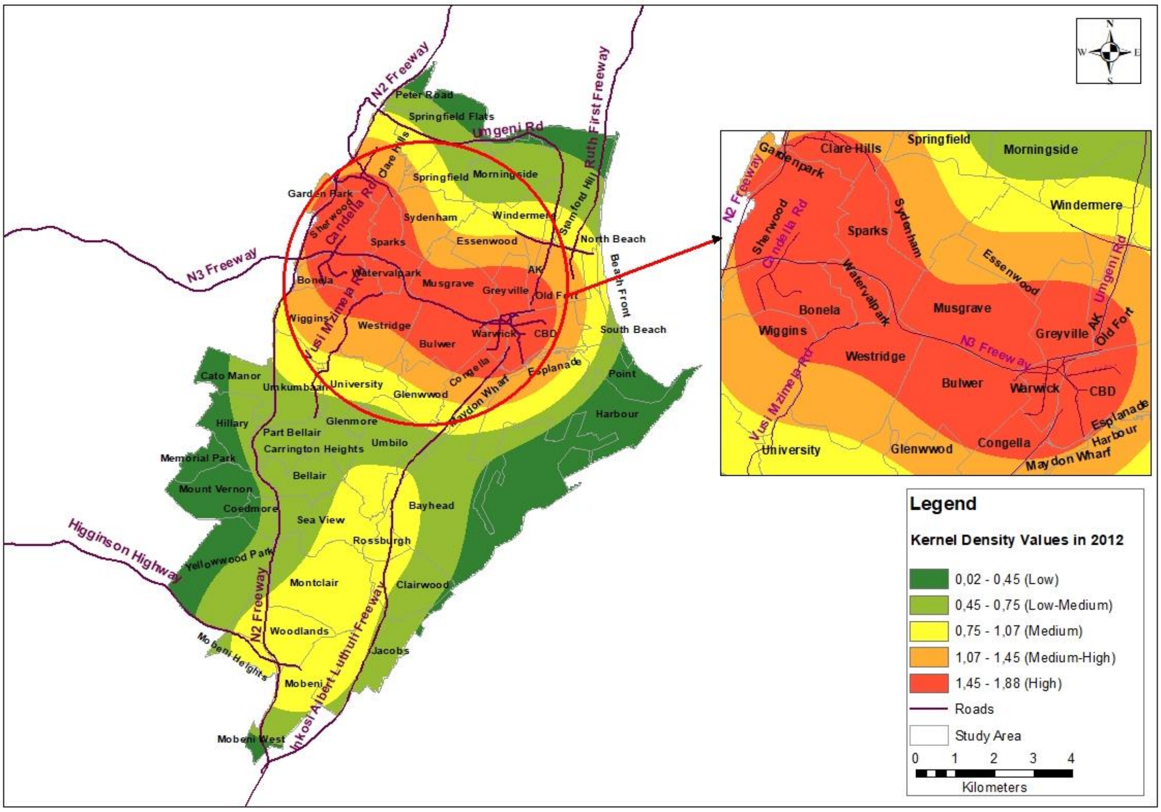

Figure 5.6 Kernel Density Estimation Analysis of Fatal Accidents in 2012 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Figure 5.7 shows hotspot locations for fatal accidents in 2012 based on Getis-Ord Gi* hotspot analysis. Of the 133 fatal accidents recorded in 2012, only 4 were identified as hotspots at 95% and 99% confidence intervals, at which 14 fatal accidents responsible for 16 fatalities victims were recorded. For statistically significant positive z-scores, the larger the z-score is and the smaller the p-value is, then the more intense the clustering of hotspots (ESRI, 2016). Clare Hills and Palmiet were identified as hotspot areas at 99% confidence interval with a z-score of 5.02 and a p-value of 0.000001, while Bonela and Sherwood were identified as hotspot locations at 95% confidence interval with a z-score of 3.22 and a p-value of 0.0013. The specific locations identified were:

1. N2 Freeway/ overhead Bridge to Clare Estate; Clare Hills (4 accidents)

2. N2 Freeway/ Shacks (Clare Estate vicinity); Palmiet (4 accidents)

3. N2 Freeway/ Westwood Mall; Sherwood (3 accidents)

4. Vusi Mzimela Road/ Cato Crest (sec near NPA building); ELP 1-7; Bonela (3 accidents).

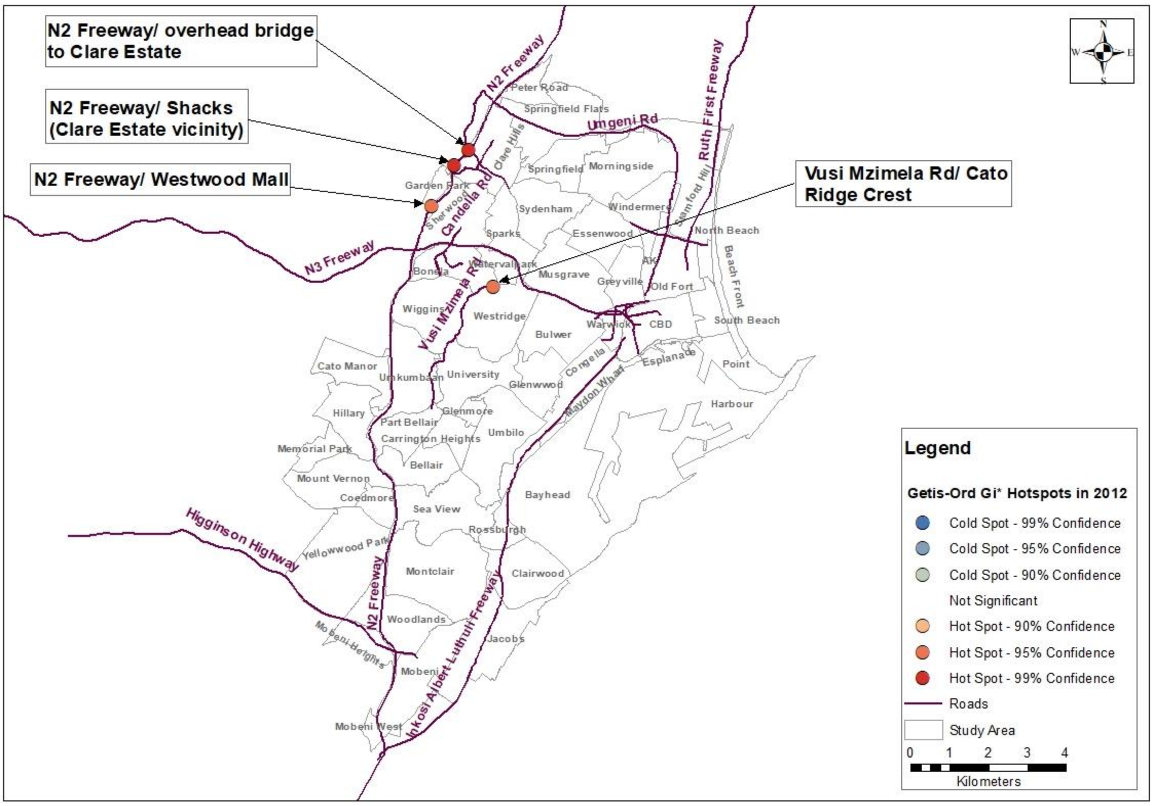

Figure 5.7 Getis-Ord Gi* of Fatal Accidents in 2012 (Data source: School of AEES and Durban City Engineers Unit).

All of the hotspot locations identified above occurred at a road outside a junction, with 11 occurring on freeways and only three on single carriageways. The lighting conditions in which these accidents occurred is equally distributed between daylight and nighttime, whether lit or unlit, while dawn/ -dusk account for 2. The proportion of fatal accidents recorded on weekdays is higher than those recorded on weekends, a finding contrary to several studies Pego (2009); Muviringi (2012); Ukoji (2014). Weekends accounted for 5 fatal accidents while weekdays recorded 9 fatal accidents in 2012. The highest fatal accidents on these hotspot locations were recorded in July (3) and December (3), followed by February, May and September (2 per month), while April and October jointly contributed to 2 fatal accidents of the total recorded. The causes of fatal accidents at the identified hotspot locations were, pedestrians entering the roadway when unsafe to do so (6), driver not noticing the vehicle or a pedestrian (2), unknown causes (2), driver taking evasive action for pedestrian and pedestrian (2), driving into rear of front vehicle (1) and one involving an emergency vehicle response. Hotspot locations determined by Getis-Ord Gi* hotspot analysis resulted from three collision types namely, vehicle-pedestrian (10), multi-vehicle rear end (3) and rear-end (1). Although Kernel density estimation can generate a simplified raster pattern of hotspot location areas, the robust and comprehensive Getis-Ord GI* hot spot analysis tool provides a better depiction of the spatial distribution of fatal accidents in the study area due to statistical significance determination of the measured points (Truong and Somenahalli, 2011; Rankavat and Tiwari, 2013).

In terms of the directional distribution of fatal accidents locations in 2012 in the greater Durban city, Figure 5.8 shows that fatal accidents were oriented in a Northeasterly-Southwesterly trend with a rotation of 19.58. This directional trend is similar to the one observed in 2011, although it shifted by a rotation of 0.57 from the previous year due to the slight increase of the location of fatal accidents in the median lateral areas.

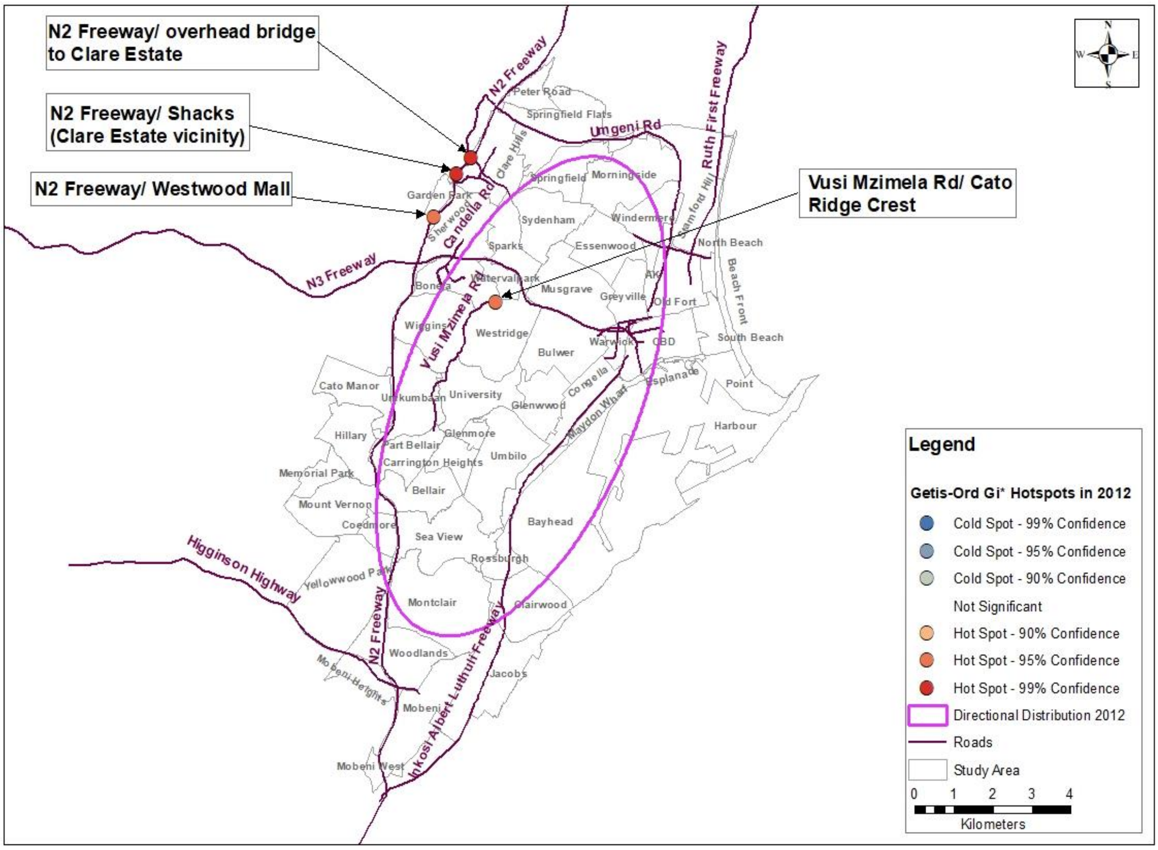

Figure 5.8 Directional Distribution (SDE) of Fatal Accidents in 2012 (See Purple ellipse).

(Data source: UKZN School of AEES and Durban City Engineers Unit).

5.4 Distribution of Road Traffic Fatal Accident Hotspots in 2013

The integrate, collect events and calculate distance functions (see Chapter 3, Section 3.5.1) were used to aggregate data and to obtain a minimum distance of 13.44m, average distance of 584.22m and a maximum distance of 2265.63m. The maximum and average distances were explored in ISA to determine the first peak at which clustering occurs in the data so it can be used for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi*. However, no peak distances were retained at any of the distances implying that the fatal accidents in this year were more randomly spread in the study area compared to the previous years. The researcher further calculated the peak distance for 2014, and the minimum, average and maximum distance values retained from the calculate distance tool were similar to those calculated in 2013. Then, ISA was executed using a peak distance of 2265.63m to determine the first peak at which clustering occurred. No clustering occurred at that distance, hence a distance of 3000m was tried and it retained a first peak distance threshold of 6795.76m. This distance was used for global Moran's I, Anselin Local Moran's I. KDE and Getis-Ord Gi* for both 2013 and 2014, since they shared similar values. The pattern of fatal accidents distribution in 2013 does not appear to be significantly different than random, given the z-score of -1.22 and a p-value of -0.63, which fall within the z-score range of -1.65 to 1.65, and a p-value range of -0.10 to 0.10 (see Chapter 3, Section 3.5.3).

To check for the existence of local clustering in the data, Anselin Local Moran's I (Chapter 3, Section 3.5.3) was done and results showed that there were no clusters or outliers of fatal accidents in 2013 (Figure 5.9). The occurrence of fatal accidents in 2013 could be attributed to complete spatial randomness.

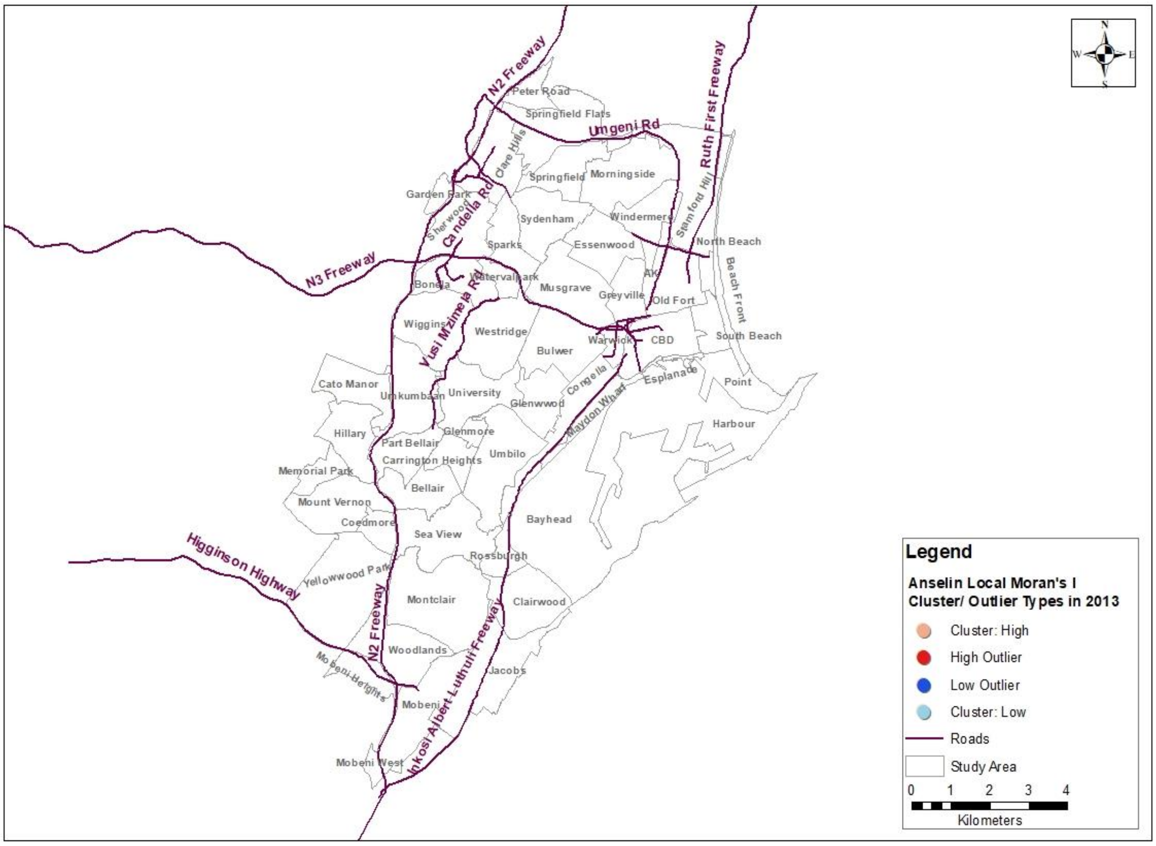

Figure 5.9 Anselin Local Moran's I of Fatal Accidents in 2013. (Data source: UKZN School of AEES and Durban City Engineers Unit).

The distance threshold of 6795.76m, derived from the collect events function and calculate distance function as discussed in Chapter 3, Section 3.5.1, was used for KDE to determine the spatial distribution of fatal accident densities in 2013. Figure 5.10 and its legend shows that hotspot locations are those with a Kernel density value of 0.59 – 0.73. These are AK, Bayhead, Bulwer, CBD, Congella, Esplanade, Essenwood, Glenwood, Greyville, Maydon Wharf, Musgrave, Old Fort, Sparks, Umbilo, Warwick and Westridge.

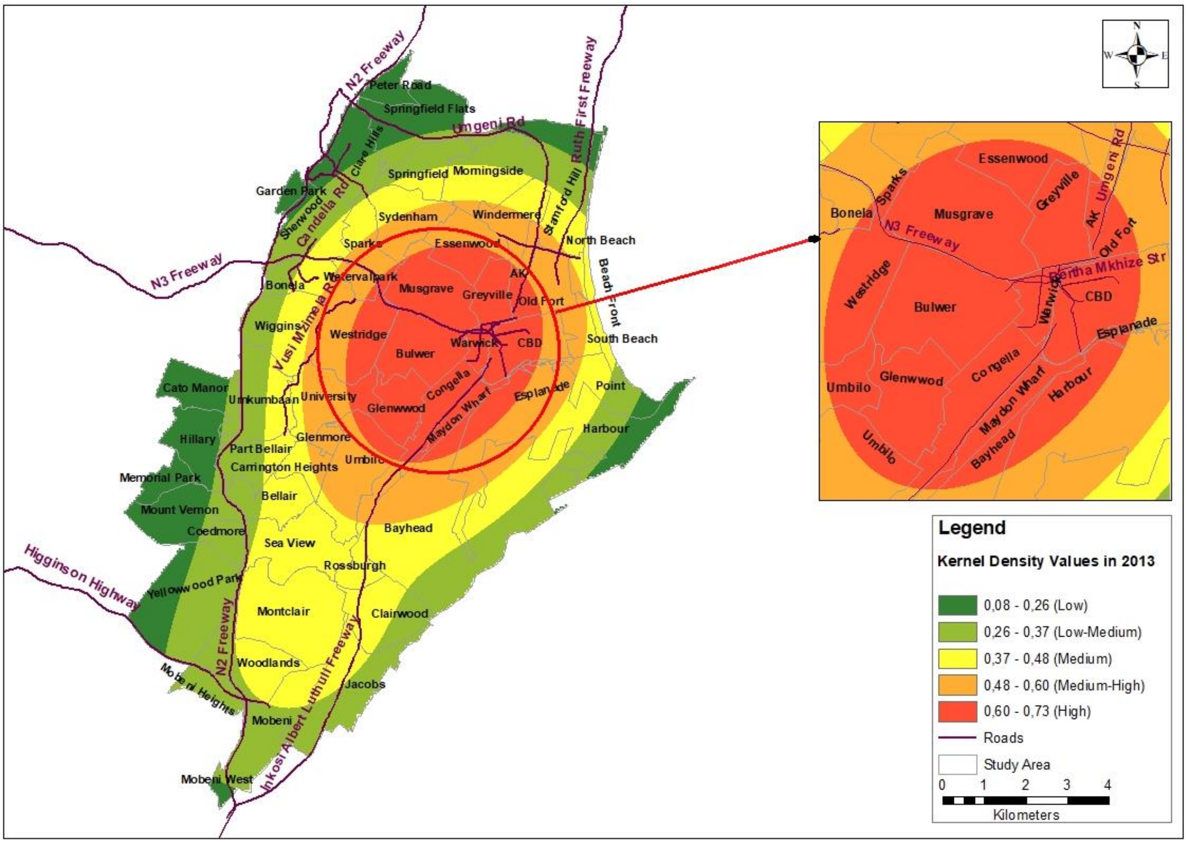

Figure 5.10 Kernel Density Estimation Analysis of Fatal Accidents in 2013 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Figure 5.11 shows hotspot locations for fatal accidents in 2013 based on Getis-Ord Gi* hotspot analysis. Four areas, namely, CBD-Albert Park, Umkumbaan, Congella, and Lamontville were identified as hotspot locations with z-scores ranging from 3.01 – 6.23 and p-values of 0-0.003. Lamontville was a hotspot location for fatal accidents at 99% confidence interval while the other three locations were hotspots at 95% confidence intervals. These hotspots were responsible for 10 fatalities victims. The specific locations identified were:

1. Joseph Nduli Street/Bertha Mkhize Street; CBD-Albert Park (2 accidents).

2. N2 Freeway/ Cato Manor; Umkumbaan (2 accidents)

3. N2 Freeway/ Lamontville; Lamontville (4 accidents

4.) Inkosi Albert Luthuli Freeway/ Khangela bridge; Congella (2 accidents).

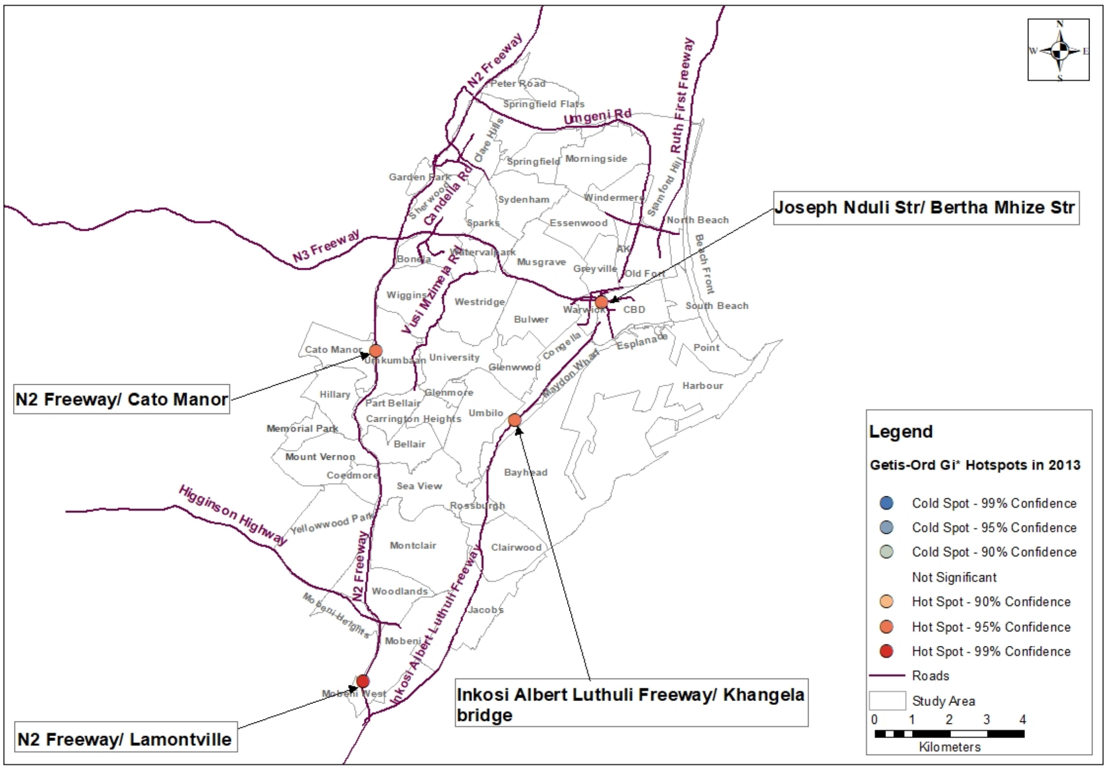

Figure 5.11 Getis-Ord Gi* Hotspot Analysis of Fatal Accidents in 2013 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Five of the fatal accidents occurred on dual carriageways, 3 on freeways and only 2 on one way road types. Dual carriageways and freeways increase the risk of fatal accidents (Mokoma, 2017), where pedestrians practice unsafe behaviours such as jaywalking, and drivers change lanes dangerously at excessive speeds (Peden *et al*. 2004; Agbonkhese *et al*. 2013). Portions of the road outside a junction recorded 7 fatal accidents, followed 2 fatal accidents on T-junction and one fatal accident on an off ramp. In terms of lighting condition, daylight accounted for 5 fatal accidents, followed by 3 fatal accidents at night-lit by street lights and 2 at dawn/-dusk. Although most fatal accidents recorded at these hotspot locations occurred during daylight, Plainis *et al*. (2006) mentioned that night-time fatal accidents are considerably high due to the driver's impeded ability to avoid collisions under dim lighting, and also attributable to pedestrians who do not wear reflective vest to enhance their visibility at night (Peden *et al*. 2004). Weekends recorded the maximum of 9 fatal accidents while Monday recorded only one fatal accidents. Weekends are marked by various social activities that lead to an increase in traffic flow and human population on the roads, and unsafe behaviours such as aggressive driving, driving under the influence of alcohol consumption and speeding, which often lead to fatal accidents (Pego, 2009). The occurrence of fatal accidents by month differs, where the highest record was in July (3), followed by January (2), while the remaining 5 were equally distributed in February, March, April, August and September. The causes of fatal accidents at the identified hotspot locations were, pedestrians entering the roadway when unsafe to do so (8) (Chiduo and Minja, 2001), driver entering the roadway when unsafe to dos (1) and one as a result of the loss of a wheel. Out of the fatal accidents recorded on these hotspots, 9 were due to a vehicle-pedestrian collision, probably due to jay walking, lack of pedestrian facilities and pedestrians entering the roadway when unsafe to do so (Gainewe and Masangu, 2012), while only one was a result of other type of collision type.

In terms of the directional distribution of fatal accidents locations in the greater Durban City, Figure 5.12 shows that fatal accidents in 2013 were sharply elongated in a Northeasterly-Southwesterly trend with a rotation of 27.76. This can be attributed to the fatal accident locations distributed from the central zone towards Lamontville.

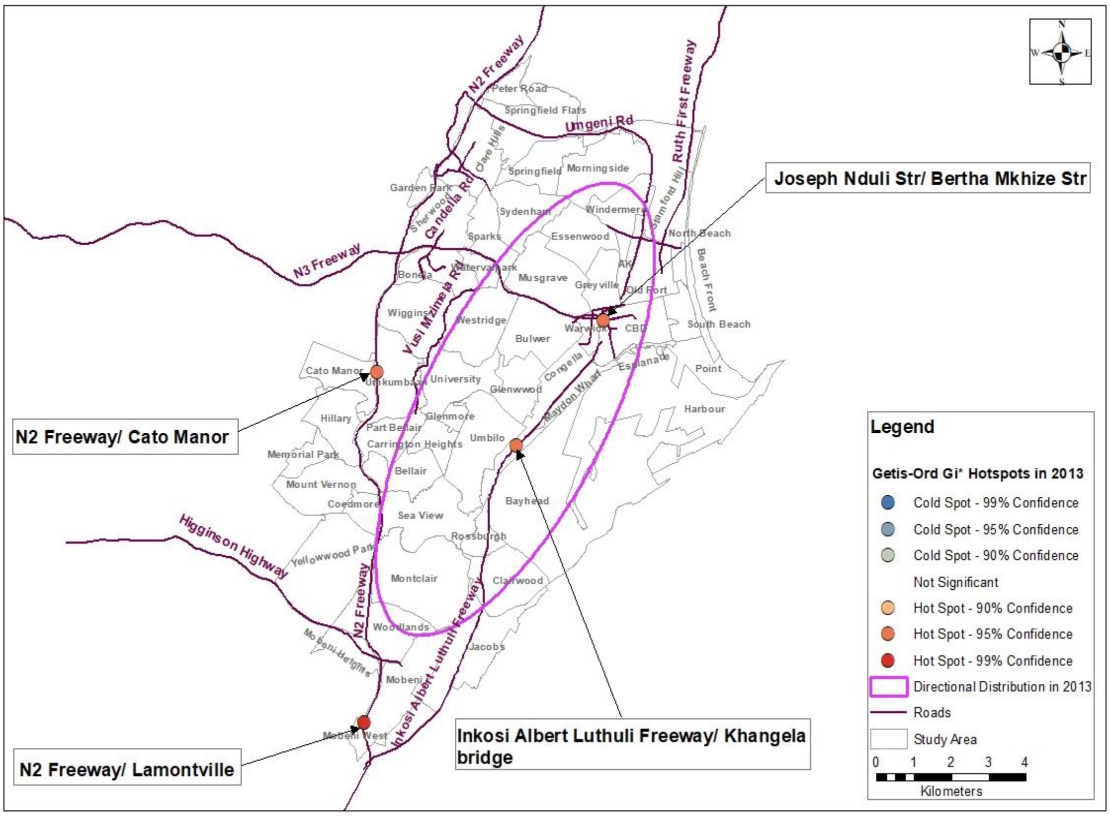

Figure 5.12 Directional Distribution (SDE) of Fatal Accidents in 2013 (See Purple ellipse). (Data source: UKZN School of AEES and Durban City Engineers Unit).

5.5 Distribution of Road Traffic Fatal Accident Hotspots in 2014

The integrate, collect events and calculate distance functions were used to obtain a minimum distance of 75.33m, average distance of 542.25m and a maximum distance of 2265.63m. The maximum and average distances were explored in ISA to determine the first peak at which clustering occurs in the data so it can be used for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi* (see Chapter 3, Section 3.5.1). However, no peak distances were retained at any of the distances. A distance of 3000m was used to execute the ISA because it was the maximum distance on the number of integrated and collected events (ESRI, 2016). A distance of 6795.76m was retained after executing ISA and it was used as a search radius for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi*. A z-score of 0.59 and a p-value of 0.55 was retained by global Moran's I spatial autocorrelation for fatal accidents in 2014. Since these values fall within the region of random distribution (Chapter 3, Section 3.5.2; Figure 3.2), the spatial pattern of fatal accidents in 2014 does not appear to be significantly different than random.

While Moran's I quantifies the spatial autocorrelation at a global scale, the local indicators of spatial association (LISA) measure the degree of spatial autocorrelation of fatal accidents at each specific location (Anselin, 1995) by using Anselin local Moran's I (Erdogan *et al*. 2015). Anselin Local Moran's I was run for fatal accidents in 2014 to determine the existence of clustering and outliers, and Figure 5.13 shows that there were no clusters or outliers of fatal accidents in the study area. This entails that fatal accidents occurred due to complete spatial randomness (ESRI, 2016).

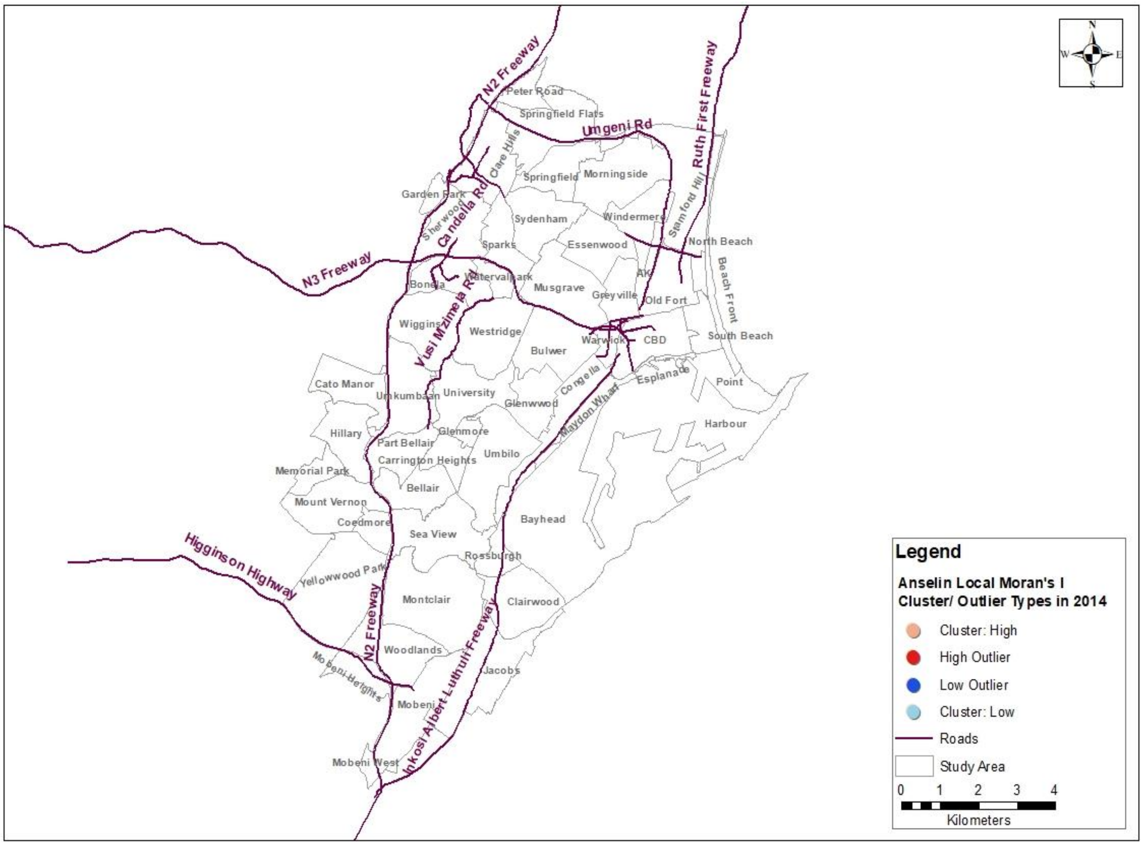

Figure 5.13 Anselin Local Moran's I of Fatal Accidents in 2014 (Data source: UKZN School of AEES and Durban City Engineers Unit).

The next step was to determine the spatial spread of fatal accidents using KDE based on the clusters generated by the collect events tool (see Chapter 3, Section 3.5.4). The KDE results in Figure 5.14 shows the locations where fatal accidents are intense based on the Epanechnikov kernel, at an inverse distance and a categorisation of inherent data by natural breaks based on the Jenks algorithm (Chapter 3, Section 3.5.4). Hotspot areas identified had a Kernel density value range of 0.81 – 1.02 (Figure 5.14 and its legend). These are A.K, Bonela, Bulwer, CBD, Congella, Esplanade, Essenwood, Glenwood, Greyville, Harbour, Maydon Wharf, Morningside, Musgrave, Old Fort, Sparks, Springfield, Sydenham, Warwick, Westridge and Winderemere.

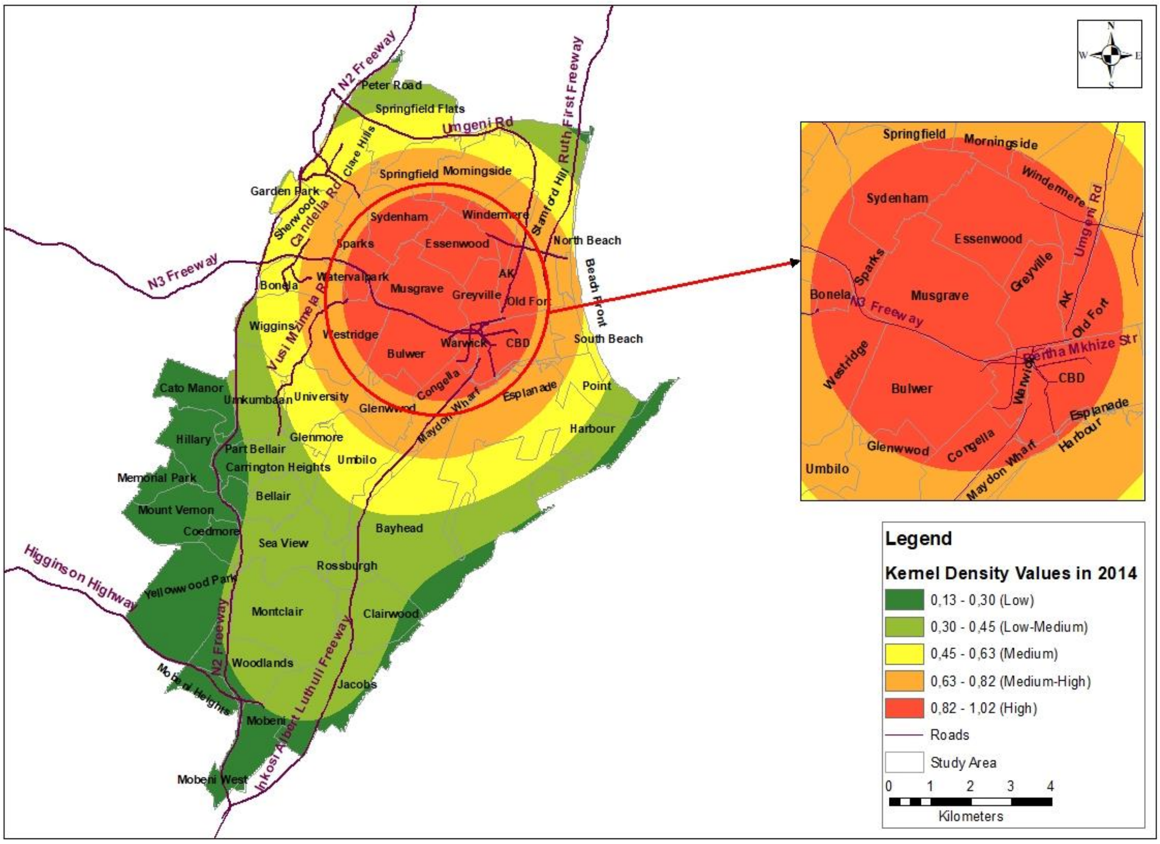

Figure 5.14 Kernel Density Analysis of Fatal Accidents in 2014 (Data source: UKZN School of AEES and Durban City Engineers Unit).

Figure 5.15 shows hotspot locations for fatal accidents in 2014 based on Getis-Ord Gi* hotspot analysis (see Chapter 3, Section 3.5.5). Seven areas, namely, Springfield, Clare Hills, Sherwood, Waterfall, Congella, Warwick-North and Stamford were identified as hotspots locations with z-scores ranging from 2.79 – 5.88 and p-values of 0-0.0052. Stamford was identified as a hotspot location for fatal accidents at 99% confidence interval while the other six locations were hotspots at 90% confidence intervals. These hotspots were responsible for 15 fatalities victims. The specific locations identified were:

1. Quarry Road/ Umgeni Road; Springfield (2 accidents)

2. N2 Freeway/ overhead bridge to Wandsbeck Road; Clare Hills (2 accidents)

3. N2 Freeway/ overhead bridge to King Cetshwayo Highway/ Westwood Mall; Sherwood (2 accidents)

4. N3 Freeway/ Brickfield Road Interchange; Waterfall (2 accidents)

5. Inkosi Albert Luthuli Freeway/ Dalbridge Station; Congella (2 accidents)

6. Johannes Nkosi Street/Dr Yusuf Dadoo Street; Warwick-North (2 accidents)

7. Sandile Thusi Road/Stalwart Simelane Street/Ruth First Highway; Stamford (3 accidents).

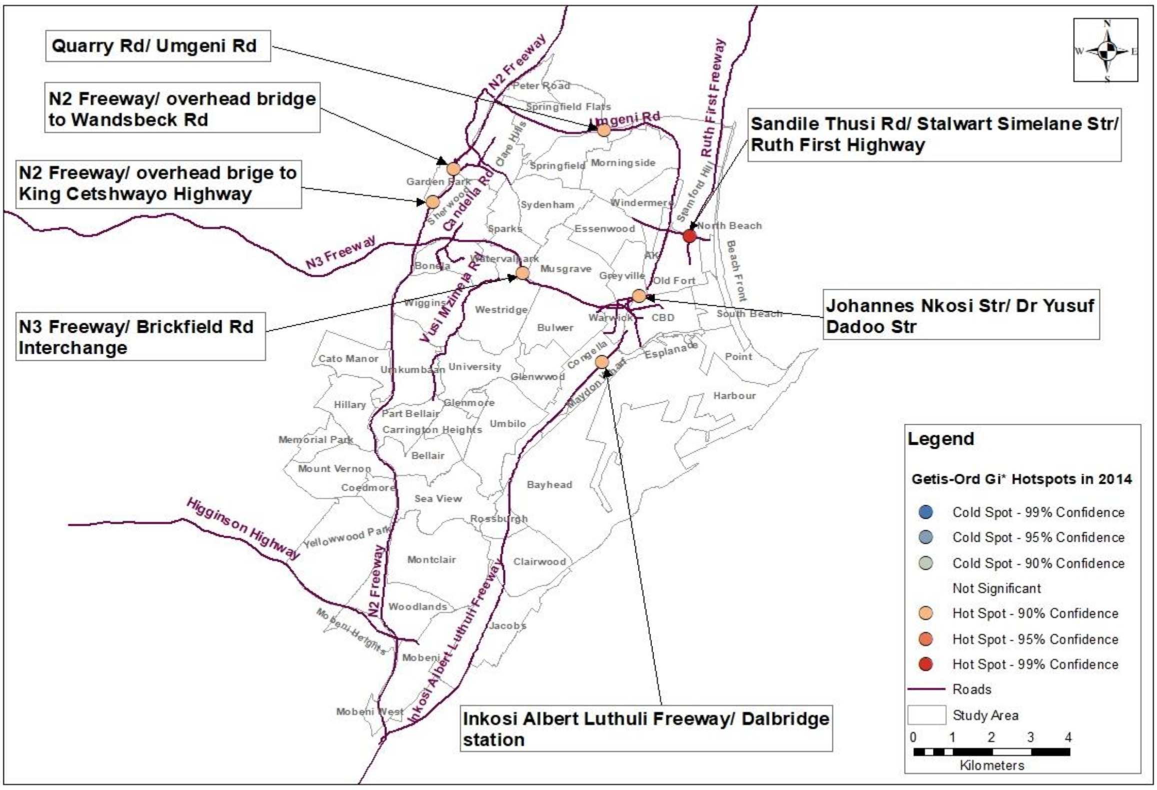

Figure 5.15 Getis-Ord Gi* Hotspot Analysis of Fatal Accidents in 2014 (Data source: UKZN School of AEES and Durban City Engineers Unit).

The type of the road plays a role in determining the occurrence of fatal accidents. Eight fatal accidents occurred on freeways, followed by 4 fatal accidents on dual carriageways, one way (2) and only one of the total fatal accidents occurring on a single carriageway. Portions of the road outside a junction recorded 8 fatal accidents, followed 5 fatal accidents on crossroads and 2 on T-junctions. In terms of lighting condition, 8 fatal accidents occurred at night whether lit or unlit, while daylight accidents were 6 and only 1 fatal accident occurred at dawn/-dusk.

Weekends recorded the maximum of 8 fatal accidents while weekdays recorded 7 fatal accidents. This finding corroborates with Pego (2009), who mentioned that most fatal accidents in Botswana occur on weekends due to an increase of young and novice drivers, who drive under the influence of alcohol, and likely to exceed speed limits. The occurrence of fatal accidents by month differs, where the highest record was in February (3) and August (3), followed by June (2) and December (2), while the remaining 5 were equally distributed in January, March, September, October and November. The causes of fatal accidents at the identified hotspot locations include, unknown causes (5), pedestrians entering the roadway when unsafe to do so (4), disregarding red traffic signal (2), and the remaining 4 equally attributed to skidding, brake failure, turning in face of oncoming traffic and failure of the driver to notice a pedestrian or another vehicle. Out of the fatal accidents recorded on these hotspots, 10 were due to a vehicle-pedestrian collision, followed by a turn right opposing collision between vehicles, whereas 2 were a result of rear-end and vehicle-object collisions.

In terms of the directional distribution of fatal accidents locations in the greater Durban City, Figure 5.16 shows that fatal accidents in 2014 were slightly elongated in a Northeasterly-Southwesterly trend with a rotation of 20.14. The trend shifted more to the north because of an intense occurrence of fatal accidents in those locations.

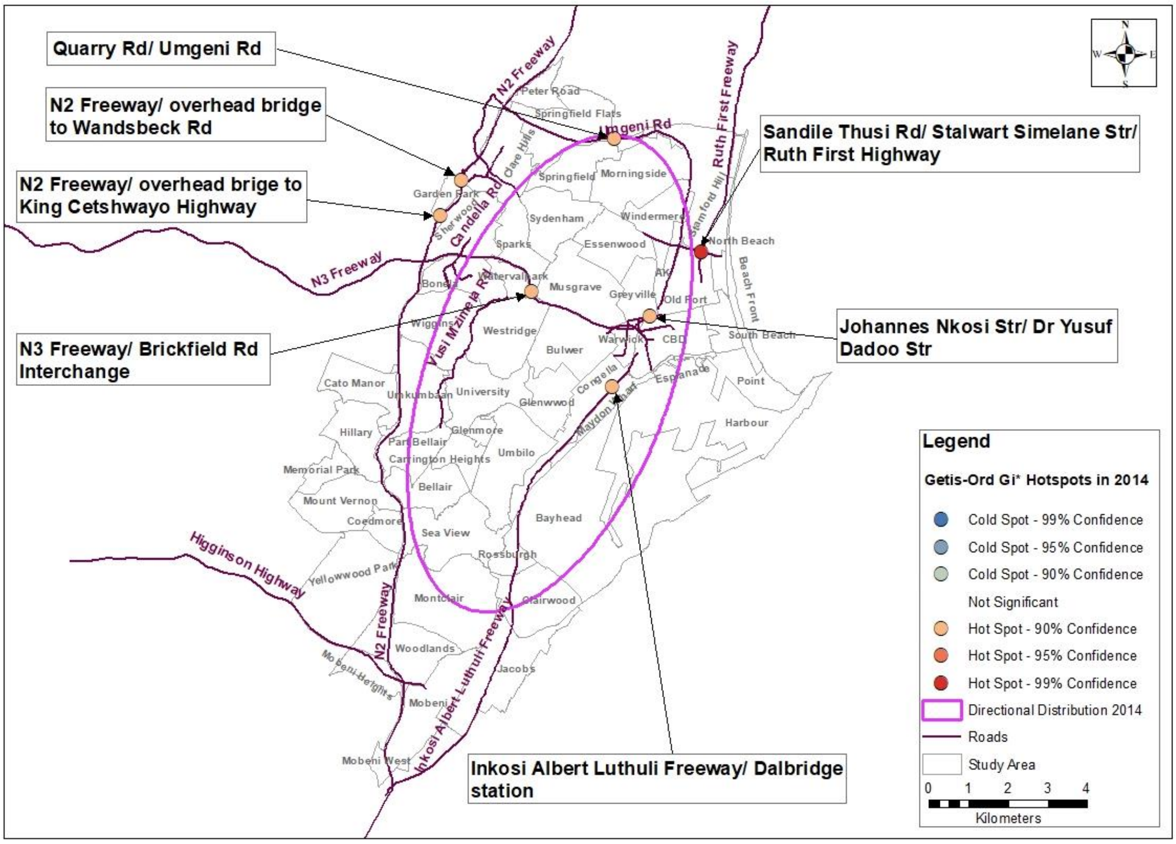

Figure 5.16 Directional Distribution of Fatal Accidents in 2014 (See Purple ellipse). (Data source: UKZN School of AEES and Durban City Engineers Unit).

5.6 Distribution of Road Traffic Fatal Accident Hotspots in 2015

The integrate, collect events and calculate distance tools were executed (see Chapter 3, Section 3.5.1), results retained were a minimum distance of 39.85m, an average distance of 446.75m and a maximum distance of 1636.32m. The maximum and average distances were explored in ISA to determine an appropriate search radius of 2051m to use for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi*. Global Moran's I retained a z-score of -0.62 and a p-value of 0.53 entailing that the distribution of fatal accidents in 2015 were random (see Figure 3.2). The null hypothesis was accepted because both the z-score and p-value fall within the range of randomness at a 90% confidence level (See Chapter 3, Section 3.5.2; Figure 3.2)

A local clustering of fatal accident location was determined by Anselin Local Moran's I (see Chapter 3, Section 3.5.3), which showed only one high outlier surrounded by low values at the Inkosi Albert Luthuli Freeway/ Rossburgh Station, with a z-score of -3.71 and a p-value of 0.0002 at a 99% confidence level (Figure 5.17). A high negative z-score and a very small p-value confirm statistical significance of outliers and surrounding high values (Anselin, 1995).

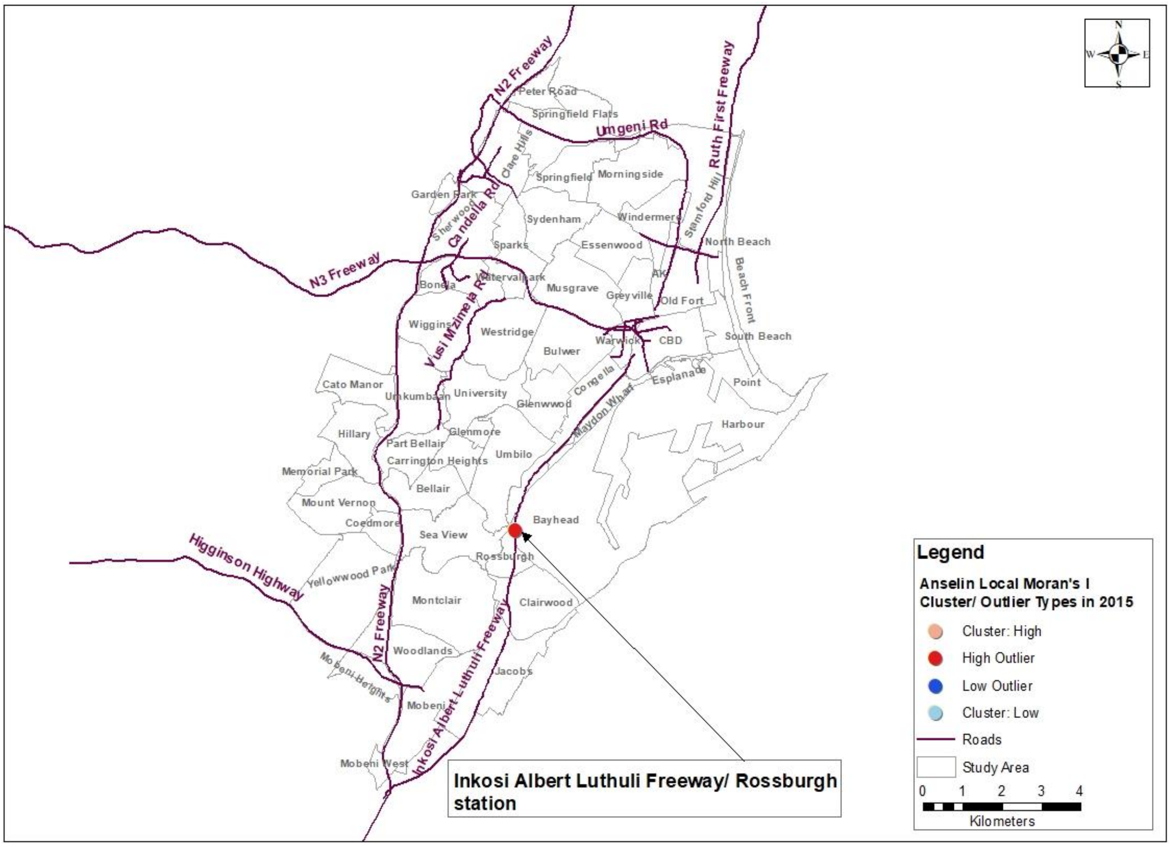

Figure 5.17 Anselin Local Moran's I of Fatal Accidents in 2015. (Data source: UKZN School of AEES and Durban City Engineers Unit).

The next step was to determine the spatial spread of fatal accidents using KDE (see Chapter 2, Section 2.6; Chapter 3, Section 3.5.4). The KDE results in Figure 5.18 shows the locations where fatal accidents are intense based on the Epanechnikov kernel, at an inverse distance and a categorisation of inherent data by natural breaks based on the Jenks algorithm. Hotspot areas identified had a Kernel density value of 2.25 – 3.72 (Figure 5.18 and its legend). These are A.K, Bulwer, CBD, Congella, Greyville, Esplanade, Harbour, Musgrave, Old Fort and Warwick.

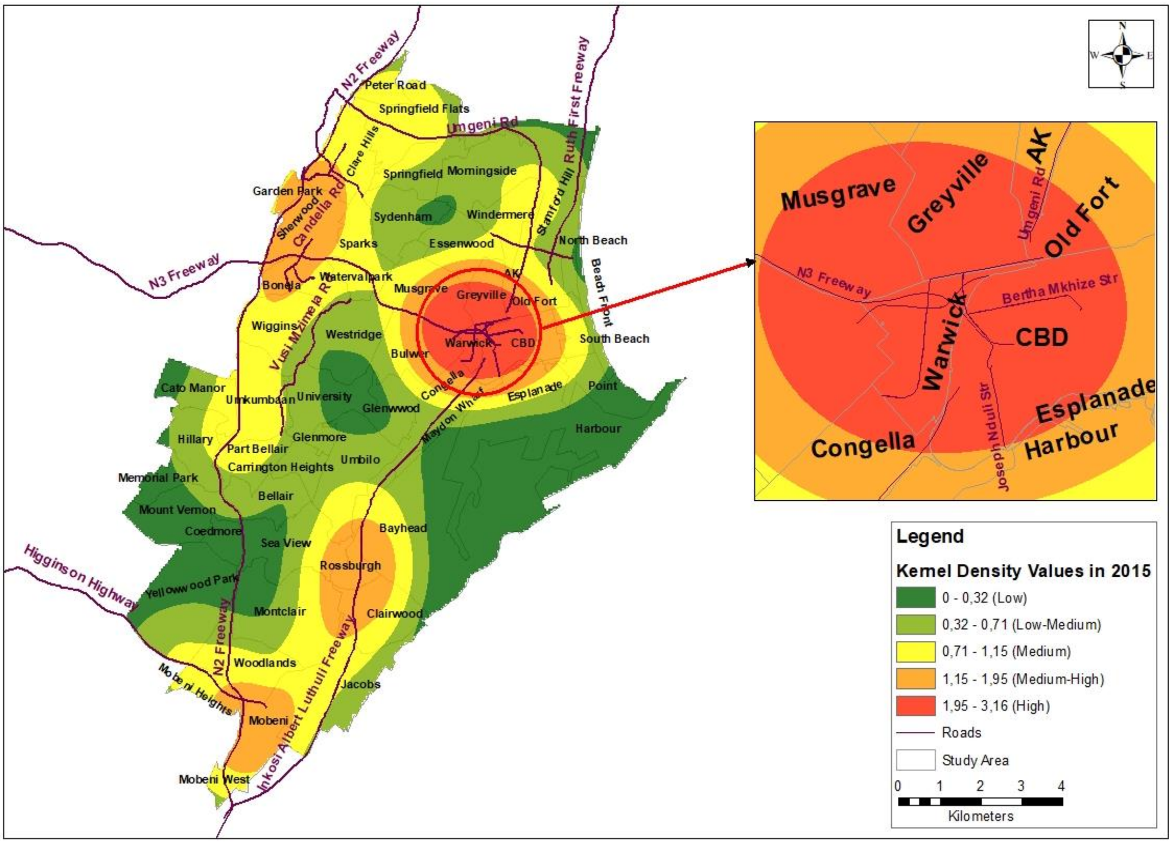

Figure 5.18 Kernel Density Analysis of Fatal Accidents in 2015. (Data source: UKZN School of AEES and Durban City Engineers Unit).

Figure 5.19 shows hotspot locations for fatal accidents in 2015 based from Getis-Ord Gi* hotspot analysis (see Chapter 2, Section 2.6; Chapter 3, Section 3.5.5). Out of 108 fatal accidents recorded in 2015, 12 accidents occurring on 4 locations at a 99% confidence level were identified as statistically hotspots with a z-score ranging from 4.13 – 4.14 and p-value of 0.00034 – 0.00035. The areas in which the hotspots for fatal accidents occurred in 2011 were Palmiet, Umkumbaan, Rossburgh and Havenside, with the specific road locations being:

1. N2 Freeway/ Shacks (Clare Estate vicinity); Palmiet (3 accidents)

2. N2 Freeway/ Cato Manor; Umkumbaan (1 accident)

3. Higginson Highway/ Traffic signal warning sign; Havenside (3 accidents)

4. Inkosi Albert Luthuli Freeway/ Rossburgh Station; Rossburgh (3 accidents).

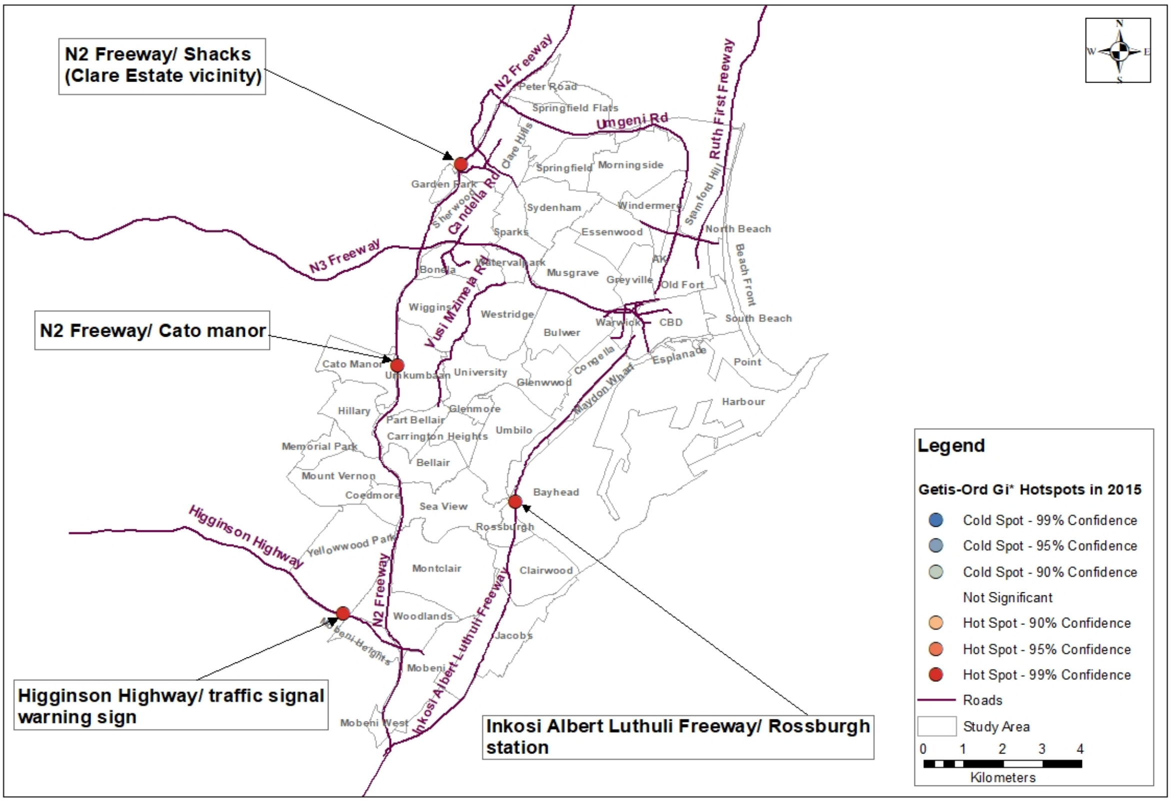

Figure 5.19 Getis-Ord Gi* Hotspot Analysis of Fatal Accidents in 2015. (Data source: UKZN School of AEES and Durban City Engineers Unit).

These hotspots occurred on highways which pass through residential areas and industrial areas, where high traffic volume and pedestrian mix increases the risk of a fatal accident occurring (ROSPA, 2017). Freeways recorded 9 fatal accidents, followed by dual carriageways (3). Weekends (10) recorded the highest fatal accidents while weekdays recorded only 2 of the total fatal accidents identified as hotspots. The months in which the fatal accidents occurred were June (4), March (2), and the following six months which jointly recorded 6 fatal accidents, January, February, April, July, November and December. Night time fatal accidents at these hotspots were 7, while daylight recorded 5 fatal accidents. The causes of fatal accidents at the identified hotspot locations were, pedestrians entering the roadway when unsafe to do so (6), and the following six causes jointly contributing to 6 of the total, speeding, skidding, jaywalking, driving into rear of front vehicle, taking evasive action for a pedestrian and unknown cause. All the hotspot locations determined by Getis-Ord Gi* hotspot analysis resulted from four collision types namely, vehicle-pedestrian accounting for 8 accidents, single vehicle overturn (2), sideswipe same direction and rear-end collisions jointly accounting for 2 accidents.

In terms of the directional distribution of fatal accidents locations in the greater Durban City, Figure 5.20 shows that fatal accidents in 2015 were sharply elongated in a Northeasterly-Southwesterly trend with a rotation of 19.76.

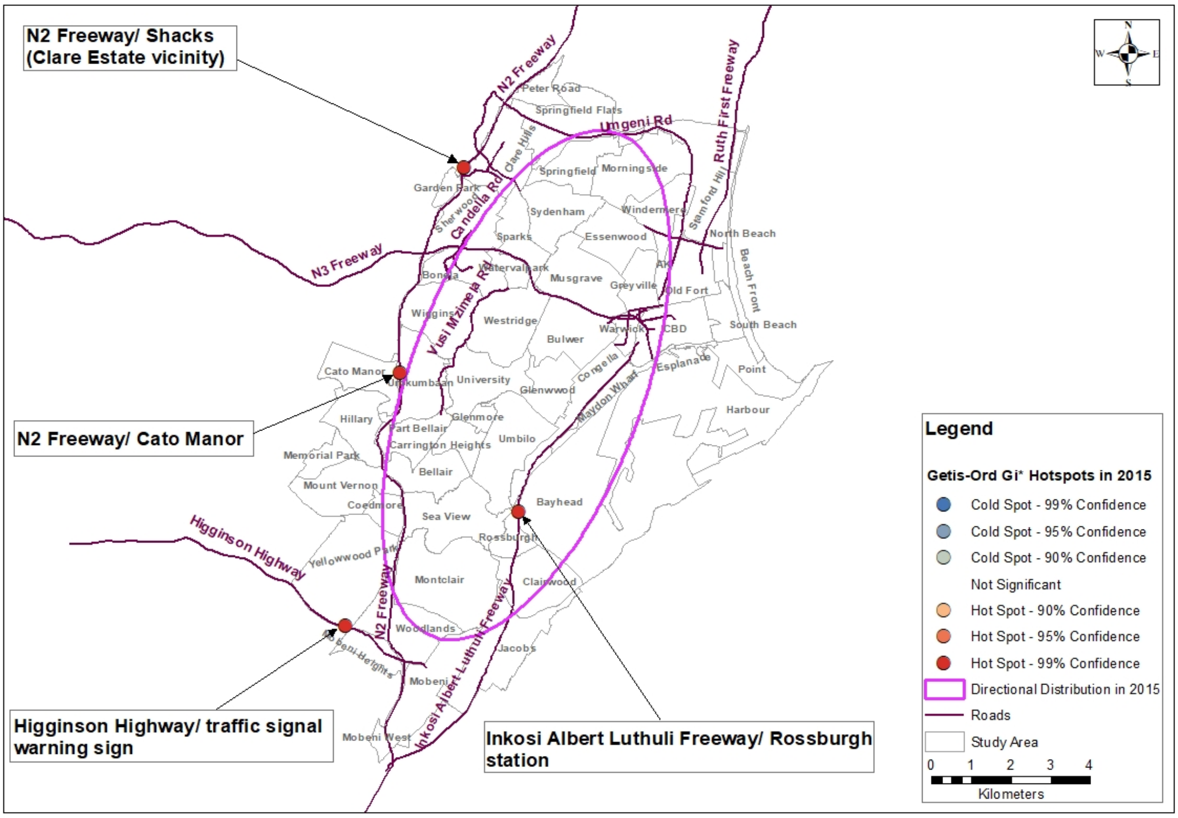

Figure 5.20 Directional Distribution (SDE) of Fatal Accidents in 2015 (See Purple ellipse). (Data source: UKZN School of AEES and Durban City Engineers Unit).

5.7 Discussion of Density/ Hotspot Patterns and Trends of Fatal Accidents

Statistical significant hotspot locations for fatal accidents were determined by Kernel Density Estimation (KDE) and Getis-Ord Gi* hotspot analysis after vetting the data for possibility of clustering using the spatial autocorrelation test (see Chapter 3, Sections 3.5.2 – 3.5.5). Prior to testing for spatial autocorrelation, data was subjected to the integrate, collect event and calculate distance functions to find an appropriate distance to use in Incremental Spatial Autocorrelation (ISA) to determine a search radius distance for global Moran's I, Anselin Local Moran's I, KDE and Getis-Ord Gi* (see Chapter 3, Section 3.5.1). While the global Moran's I showed that fatal accidents occur randomly in the study area with the exception of 2012 which showed a 99% likelihood that accidents occurred due to underlying spatial processes other than random, the Anselin Local Moran's I identified areas of possible clustering for further analysis using the Kernel density analysis and Getis-Ord Gi* hotspot analysis. Although global Moran's I and Anselin Local Moran's I test for clustering in data, they do not explain why locations that have clusters of statistically significant accidents have higher incidence of fatalities than other locations (Mitra, 2009). Hence, the need for KDE and Getis-Ord Gi* hotspot analysis (Anderson, 2009; Oris, 2011; Rankavat and Tiwari, 2013).

Kernel Density Estimation (KDE) lies in determining the risk spread of fatal accidents (Anderson, 2009), by calculating the density of accidents in a neighbourhood surrounding those accidents by assigning weights (Asgary *et al*. 2010). However, this method lacks statistical significance of features (Anderson, 2009). KDE maps revealed that the Warwick and CBD areas are hotspots for fatal accidents, due to a high mix of vehicles and pedestrians on the freeways, dual carriageways and one ways, which hosts more lanes, a high traffic volume travelling at high speeds (Mokoma, 2017). Moreover, there is a likelihood of increased aggressive driving (Pego, 2009) resulting from high congestion, which subsequently leads to fatal accidents due to unsafe manoeuvres. Moreover, distracted driving and inattention by pedestrians can be attributable to the higher fatal accidents in the Warwick and CBD areas. Distractions likely to increase the risk of fatal accidents include paying attention to billboard signs, receiving phone calls or text messaging, plugging of earphones while listening to music, applying makeup, eating, interaction with passengers and alcohol consumption while driving or walking (Agbonkhese *et al*. 2013).

KDE detected hotspots, some which were also determined by Getis-Ord Gi* as statistically significant hotspots (see Chapter 2, Section 2.6). The Getis-Ord Gi* hotspot maps show that out of all fatal accidents recorded from 2011 – 2012, only 22 were identified as hotspots at 90%, 95% and 99% confidence intervals, resulting in 59 fatalities. Hotspot locations and their characteristics vary each year, although the N2 Freeway appears consistently throughout the five-year period under study and accounting for 49.2% (29) of the total recorded fatalities. Some of the hotspot locations ranked among the highest based on the number of fatalities are N2 Freeway/ Westwood Mall, N2 Freeway/ Shacks (Clare Estate vicinity), N2 Freeway/ overhead bridge to Clare Estate, N2 Freeway/ Cato Manor and Canongate Road/ Julius Nyerere Avenue/ David Webster Road. Freeways consistently appear as hotspot locations for fatal accidents throughout the five year period under study because they have more lanes, host high traffic volumes travelling at high speeds (see Chapter 2, Section 2.4.1.3; Section 2.4.3.2), which increase unsafe driving behaviours, such as changing lanes dangerously resulting in vehicle-vehicle collisions or vehicle-object collisions. Pedestrians crossing at freeways increase their chance of being involved in a fatal collision as drivers do not anticipate their presence (Riyad and Myeza, 2002; Peden *et al*. 2004). Most of these fatal accidents occurred in clear weather conditions, at night unlit by street lights where most informal settlements are located (Riyad and Myeza, 2002), where pedestrians were the leading cause of fatal accidents by entering the roadway when it was unsafe to do so and the inability of the driver to notice the pedestrian due to their non-wearing of reflective vests (Peden *et al*. 2004).

Vehicle-pedestrian collisions accounted for most fatal accidents at these hotspots, followed by rear-end collisions, turn right opposing and multi-vehicle rear end collisions. Most of these fatal accidents occurred on weekends, particularly on Saturdays and Fridays. Weekends are the days of the week on which most fatal accidents occur due to an increase of social activities, alcohol consumption and, also an increase in inexperienced drivers (Chiduo and Minja, 2001; Muviring, 2012). Monthly distribution of these vary per year, although on overall, July recorded the highest fatal accidents followed by February, December, June, May and September. Fatal accidents in the greater Durban City are oriented in a Northeasterly-Southwesterly directional trend throughout the years under study, although the rotation angle differs in each year due to the shift in accident intensity.

5.8 Conclusion

This Chapter has presented the spatial autocorrelation of fatal accidents within the greater Durban City from 2011 -2015, based on global Moran's I and Anselin Local Moran's I. These measures of spatial autocorrelation showed that fatal accidents occur due to random processes, with the exception of 2012 which recorded fatal accidents due to underlying spatial processes at a 99% confidence interval. The study also presented the distribution of fatal accidents densities and hotspot locations based on KDE and Getis-Ord Gi*. KDE detected the Warwick and CBD as high densities of fatal accidents, although this function lacks statistical significance. Getis-Ord Gi* hotspot analysis statistically detected 22 hotspot locations which accounted for 59 fatalities. The N2 Freeway is of critical concern as it accounted for 29 fatalities. The next Chapter, presents overall findings of this study in relation to the aim, objectives and research questions identified, and suggests recommendations that could be implemented in the greater Durban City to prevent and reduce road traffic fatal accidents.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

A review of the aim and objectives of this study is essential to establish whether they have been achieved. The research aim listed in Chapter 1, Section 1.3.1 was to identify, map and examine the spatiotemporal patterns and trends of road traffic accident fatal accidents and hotspots in the greater Durban City using GIS techniques from 2011 to 2015 and to provide possible recommendations that can be implemented to improve road safety in the study area. This aim has been met as presented in Chapters Four and Five. Chapter Four examined the spatiotemporal patterns and trends of road traffic fatal accidents, while Chapter Five identified, mapped and analysed the fatal accident hotspots in the greater Durban City from 2011 – 2015. The research has attempted to respond to the objectives as recapped below.

6.2 Summary of Findings

6.2.1 Objective 1 - To identify, map and examine the spatial patterns and trends of road traffic fatalities and hotspots in the greater Durban City from 2011 – 2015.

6.2.1.1 Spatial Patterns and Trends of Road Traffic Fatal Accidents from 2011 – 2015

Section 4.27 examined the occurrence of fatal accidents by road type and results reveal three critical road types at which highest fatal accidents occurred from 2011 - 2015. These are dual carriageways (30.4%), freeways (26.7%) and single carriageways (25.8%) as shown in Figure 4.7. However, the largest proportion of fatal accidents occurred on single carriageways (34.3%) in 2015 alone than on dual carriageways (Appendix 4.6e). The high record of fatal accidents on highways can be attributed to the fact that these roads are wider and host more traffic lanes, and these tend to encourage the increase of motor vehicle traffic speed, which increases the risk of an accident occurring (Mokoma, 2017). Furthermore, pedestrian fatality risk increases due to a high mix of vehicles and pedestrians who walk along or cross these roads at undesignated crossing points (WHO, 2013).

Fatal accidents by road surface type was examined in Section 4.28 and results in Figure 4.8 show that a majority of these occurred on dry road (93.0%), followed by wet roads (5.7%). A similar pattern and trend was observed in the annual analysis (Appendices 4.7a – 4.7e). This trend can be attributed to enhanced safety consciousness during the rainy season and a lessened road safety cautious behaviour in dry seasons. The summary Table 4.1 in Section 4.28 indicates that 99.6% of fatal accidents from 2011 – 2015 occurred on tarmac surfaces, while concrete and unknown road surfaces jointly contributed to 0.4%.

Section 4.29 examined the influence of junction type and junction control type on the occurrence of road traffic fatal accidents from 2011 – 2015, and results reveal that majority (60.8%) of fatal accidents occurred at portions of the road which is not a junction, followed by 20.1% at crossroads and 12.6% at T-Junctions from 2011 – 2015 (Figure 4.9a). A similar pattern and trend was observed in the individual yearly analysis, with the exception of 2011 whereby the second highest of fatal accidents was at T – junctions rather than on crossroads (Appendices 4.8a – 4.8e). Furthermore, the occurrence of fatal accidents at crossroads and T-junctions may be attributable to the fact that drivers and pedestrians disregard red traffic signs at robot-controlled junctions (26.7%) or at a stop sign (5.3%), yield sign (2.7%) and 5.5% at uncontrolled junctions as shown in Figure 4.9b and Appendices 4.9a – 4.9e.

6.2.1.2 Spatial Patterns and Trends of Road Traffic Fatal Accident Hotspots from 2011 - 2015

Identifying fatal accident clusters within the greater Durban City using GIS-aided technique can highlight contributory factors that can assist the government and its agencies to implement corrective measures to make driving safe at such spots and improve these roads. The spatial patterns and trends of road traffic fatalities hotspots within the greater Durban City were identified based on Kernel Density Estimation (KDE) analysis and Getis-Ord Gi* hotspot analysis. The results show that there were different levels of densities from Kernel density analysis and levels of confidence derived from Getis-Ord Gi* hotspots analysis based on the data for each year. KDE identified the one ways and dual carriageways at Warwick and CBD as common hotspot locations in the study area throughout the years, while Getis-Ord Gi* hotspot analysis statistically identified the N2 Freeway as the critical type of road on which fatal accidents occur, which accounted for 49.2% of fatalities from 2011 – 2015. Overall, the highest fatalities at identified accident hotspot locations occurred on Freeways (35) , followed by dual carriageways (13), one ways (7) and the least fatal accidents (4) occurred on single carriageways. The majority of fatalities occurred on portions of the road other than a junction or a pedestrian crossing (44), followed by crossroads which accounted for (9 fatalities), T-junction (4) and the lowest fatalities were recorded on off ramps (2). All hotspot locations occurred on tarmac road surfaces, whether on dry or wet rod surfaces.

6.2.2 Objective 2 - To identify, map and examine the temporal patterns and trends of road traffic fatalities and hotspots in the greater Durban City from 2011 – 2015.

6.2.2.1 Temporal Patterns and Trends of Road Traffic Fatal Accidents from 2011 – 2015

Section 4.3 analysed the occurrence of fatal accidents according to time in 6-hour interval blocks and Figure 4.2 shows that the majority of fatal accidents from 2011 – 2015 occurred in the 18:00 -23:59 time block (33%). This could be attributed to fatigue and failure to adhere to road rules and regulations (Muviringi, 2012). This trend was also observed for the individual yearly analysis as presented in Appendices 4.1a, 4.1d and 4.1e, while Appendices 4.1b and 4.1c show that the majority of fatal accidents were recorded in the 12:00 – 17:59 time block interval. Figure 4.2 shows that the lowest fatal accidents from 2011 – 2015 occurred in the 00:00 – 05:59 time block, and a similar trend was observed in Appendices 4.1a - 4.1c and 4.1e. However, Appendix 4.1d indicates that the lowest fatal accidents occurred in the 06:00 – 11:59 time block.

Section 4.4 analysed the occurrence of fatal accidents according to lighting conditions and the results in Figure 4.3 shows that 45.1% of these were recorded during daylight, followed by 37.5% during the night (lit by street lights). A similar pattern and trend was observed for the individual years under study as presented in Appendices 4.2a – 4.2e.

Section 4.5 looked at the effect of weekdays and weekends on the occurrence of fatal accidents from 2011 – 2015, and the results in Figure 4.4 show that weekends (52.4%) experienced more fatal accidents than weekdays (47.6%). Appendices 4.3a – 4.3e also show that weekends dominate in the occurrence of fatal accidents, due to the fact that there is an increased human and vehicle population on the roads, alongside an increased alcohol consumption and use of drugs such as cocaine, cannabis and heroin, which result in an increased risk of fatal collisions.

Section 4.6 focused on the occurrence of fatal accidents according to calendar months and the results in Figure 4.5, show that May and December had the highest record (10.1% each) of fatal accidents from 2011 – 2015, followed by March and June which recorded 9.5% each, while the lowest record was in November (5.0%). Fatal accidents in these months could be attributable to an increase in the number of unlicensed and inexperience drivers reflecting the need for travel (Sukhai *et al*. 2011), and the need to raise more money by commercial drivers by completing several trips due to speeding, regardless of fatigue (Komba, 2006). The pattern of highest month for fatal accidents varies between the years under study, however, May, July and December are among the common months in which most fatal accidents occur as presented in Appendices 4.4a – 4.4e.

Section 4.7 analysed the effect of weather conditions on the frequency of fatal accidents in the period under study and the results in Figure 4.6 show that the majority of these occurred in clear weather conditions (91.9%), followed by rainy conditions (5.3%), while 2.4% were recorded when the sky was overcast and only 0.4% occurred in undisclosed weather conditions. A similar trend was observed for the individual yearly analysis (Appendices 4.5a – 4.5e).

6.2.2.2 Temporal Patterns and Trends of Road Traffic Fatal Accidents Hotspots from 2011 – 2015

The temporal patterns and trends of road traffic fatalities hotspots within the greater Durban City were identified based on Getis-Ord Gi* hotspot analysis. The results show that there were different levels of confidence derived from Getis-Ord Gi* hotspots analysis based on the data for each year. However, the majority of fatalities occurred on weekends (36) while weekdays contributed to 23 fatalities. Also, the months in which fatalities occurred vary, with the highest fatalities occurring in July (9), followed by February (8), June and December, both accounting for an equal share of 6. The lowest fatalities were recorded in October and November, with a joint contribution of 4. A disproportionate share of fatalities were recorded in varying weather conditions, with the highest occurring in clear weather conditions (52), followed by rainy conditions 96) and the lowest fatality (1) recorded when the sky was overcast. The majority of fatalities were recorded in nighttime, whether lit or unlit by street lights (30), although 21 of these occurred when the streets were lit. Daylight fatalities recorded in the five year period under study were 23, while only 6 were recorded either dawn/ dusk.

6.2.3 Objective 3 - To determine the causative factors of road traffic accident fatal accidents in the greater Durban City from 2011 – 2015.

6.2.3.1 Causative Factors of Road Traffic Fatal Accidents in the greater Durban City from 2011 - 2015

Section 4.2.10 examined the occurrence of fatal accidents by type of collision, and the results in Figure 4.10 reveal that the largest proportion of these was due to a vehicle-pedestrian collision (67.9%), followed by vehicle-fixed object collision (10.1%), rear-end collision (4.6%) and right angle straight collision (3.3%) (Figure 4.10). Furthermore, Section 4. 2.11 and Figure 4.11 show that the leading causes of fatal accidents are human factors (92.5%), followed by unknown causes (4.9%), vehicle characteristics (2.02%) and road-environment factors (0.2%). Out of the 92.5% of human factors induced road traffic fatal accidents recorded in the greater Durban City from 2011 – 2015, several high risk behaviours were identified. These include; pedestrians entering the roadway when unsafe to do so (44.1%), driver losing control of the vehicle/ skidding (12.1%), failure of the driver to notice pedestrians or another vehicle (6.0%), disregarding red traffic signal (4.6%), speeding (4.2%) and jaywalking (4.2%) (Section 4.2.11.1 and Table 4.2). Results show that pedestrians are the most vulnerable road users and that measures to reduce the pedestrian involvement in fatal accidents must be given priority (Chiduo and Minja, 2001). Section 4.2.11.2 and Table 4.2 showed that 2% of the vehicle characteristics induced fatal accidents, and brake failure contributed 5 of these while other mechanical defects were responsible for 3 fatal accidents from 2011 – 2015. Section 4.2.11.3, Figure 4.11 and Table 4.2 reveal that only 0.2% of all fatal accidents recorded in the greater Durban City from 2011 – 2015 occurred due to road-environment factors, specifically an object thrown or which fell into a vehicle. The primary data lacked factors related to road geometry or shape, among others, which could aid in-depth analysis on the contribution of road-environment factors to fatal accidents. However, the following sections, although not categorised as causes of accidents per se in the primary data, provide information on the road-environment factors' influence on the occurrence of fatal accidents: Section 4.2.2 on fatal accidents by time, Section 4.2.3 on fatal accidents by lighting conditions, Section 4.2.6 on fatal accidents by weather conditions, Section 4.2.7 on fatal accidents by road type, Section 4.2.8 on fatal accidents by road surface type and description and Section 4.2.9 on fatal accidents by junction control and junction control type.

6.3 Conclusion

Using GIS as a platform to conduct research was fundamental as it enabled the efficient manipulation, analysis and visualisation of road accident spatiotemporal data (Anderson, 2009). This study showed that GIS techniques are useful in identifying, mapping and examining road traffic fatal accidents and associated hotspot locations within the eThekwini Municipality. The composition of road traffic fatal accidents in the greater Durban City shows a reduction of 49 accidents from 2011 -2013, and an increase of 33 fatal accidents from 2013 – 2015. An increase in the number of fatal accidents is an indication that road users are not adhering to road rules and regulations or that there is less enforcement of road rules by traffic officials. This study also showed that pedestrians are the most vulnerable road users who put their lives at risk by entering the roadway when unsafe to do so. Out of the 546 fatal accidents recorded in the greater Durban City from 2011 – 2015, 22 locations were identified as hotspot locations by Getis-Ord Gi* hotspot analysis at 90% - 99% confidence interval. The N2 Freeway is of critical concern which consistently appeared throughout the years under study, and accounting for 49.2% fatalities. The trend of these results provides evidence that the greater Durban City is not on track towards reducing road accident deaths by 50% in 2020 if road traffic fatal accidents keep increasing, revealed by the patterns and trends from this study.

6.4 Recommendations to Improve Road Safety in the greater Durban City

RTAs have become a global problem impacting on health, claimed lives, damaged property and negatively impacted on the economy. To address this problem, the United Nations declared the period 2011 – 2020 a Decade of Action for Road Safety, calling upon governments of various countries to implement measures that could improve road safety and save lives (WHO, 2013). In line with this, the eThekwini Municipality has implemented various measures to improve road safety such as those focusing on speeding, driving under the influence of alcohol, vehicle inspections and specific restraints such as the use of seat belts. These have been fruitful to some degree as this study revealed that only seven fatal accidents occurred due to alcohol intoxication and that speeding comprised of 4.2% of the total fatal accidents recorded from 2011 – 2015. However, focus should be on emerging causative factors such as the risk of entering the roadway when unsafe to do so by pedestrians, jaywalking and skidding. Okafor *et al. (*2014) asserts that in this Decade of Action for Road Safety, country specific problems should be identified and specific interventions implemented to achieve set goals. In accordance with this suggestion, the following recommendations are proposed:

6.4.1 Improve Road Traffic Accident Reporting Template

This study showed that the use of Geographic Information System can help in understanding variations in road traffic accident occurrence, while at the same time identifying locations and neighborhoods with unusually higher accidents frequency. However, there is a gap in data capture as it lacks some factors which could enable a detailed analysis inclusive of all probable causes. As such, the road traffic accident database should be expanded to incorporate variables such as age and sex of the driver, pedestrian or passengers involved in a fatal accident, whether the driver was licensed or not and the type of vehicle involved in the collision, among others.

6.4.2 Develop a GIS web-based Road Traffic Fatal Accident Hotspot Locations

There is need to develop a GIS web-based hotspot locations application (app) for road traffic fatal accidents which will be regularly updated as fatal accidents occur. This is essential in informing the road traffic safety officers of where resources are needed most. Moreover, a free website application could be developed to capture these fatal accidents and made public via the internet or mobile devices to update all road users of dangerous locations so as to exercise cautions in those areas.

6.4.3 In-depth Research on Road Accident Contributing Factors

This study focused on identifying and examining patterns and trends of fatal accidents, and hotspot locations resulting from various factors. However, there is need for further research on each of the identified contributing factor associated with road traffic fatalities to provide detailed information essential for the revision of the present road traffic policies and road safety awareness programmes aimed at reducing road accidents and fatalities.

6.4.4 Enforcement of Adherence to the Use of Pedestrian Sidewalks, Underpasses and Bridges

This study identified pedestrians as one of the main factors behind fatal accidents occurrence in the greater Durban City as they enter the roadway at unsafe locations. Therefore, pedestrian safety should be an integral part of the road construction project cycle. Authorities must allocate more resources to pedestrian safety investigations and infrastructure provision and maintenance. Furthermore, to minimise the risk of pedestrians being involved in road traffic accidents and associated injuries/ fatalities, there is need for strict enforcement of adherence to the use of pedestrian sidewalks, underpasses and bridges to avoid vehicle and pedestrian mix especially on busy roads by traffic officials through making culprits to pay a fine. Pedestrian underpasses and bridges should be monitored by security personnel to prevent criminal activities from sprouting.

6.4.5 Regular Vehicle Road Worthiness Checks

The government should enforce compulsory periodic vehicle testing, of about 2 years, for road worthiness on all vehicles. Traffic officials should regularly conduct vehicle checks especially on weekends to ensure that culprits of traffic regulation offences pay a fine as stipulated by the Administrative Adjudication of Road Traffic Offences (AARTO). In addition, it is the responsibility of vehicle drivers to adequately inspect their vehicles for any faults every morning before takeoff. Such inspections include the functionality of foot and park brakes, clutch pedal for manual vehicles, radiator water level, engine oil level, indicator lights, wiper blades and tyre pressure, among others. Videos of reconstructed fatal accidents resulting from poor maintenance of the vehicle and not conducting regular vehicle checks to be broadcasted on the television or in public places such malls, to remind drivers practice good road safety conducts.

6.4.6 Road Safety Education/ Awareness Campaigns

The municipality should initiate community based projects directed at addressing the consequences of non-use of pedestrian bridges and pavements, together with the benefits thereof. Companies and schools should allocate at least 5 minutes on road safety talks every Mondays and Fridays before the day ends, to remind everyone of the benefits of practicing good road behaviours, to be vigilant of road hazards and how to avoid them. Furthermore, a comprehensive road safety education programme should be included as part of a school's curriculum by the Department of Education across the country as it is likely to entrench good culture of traffic safety in the citizens.

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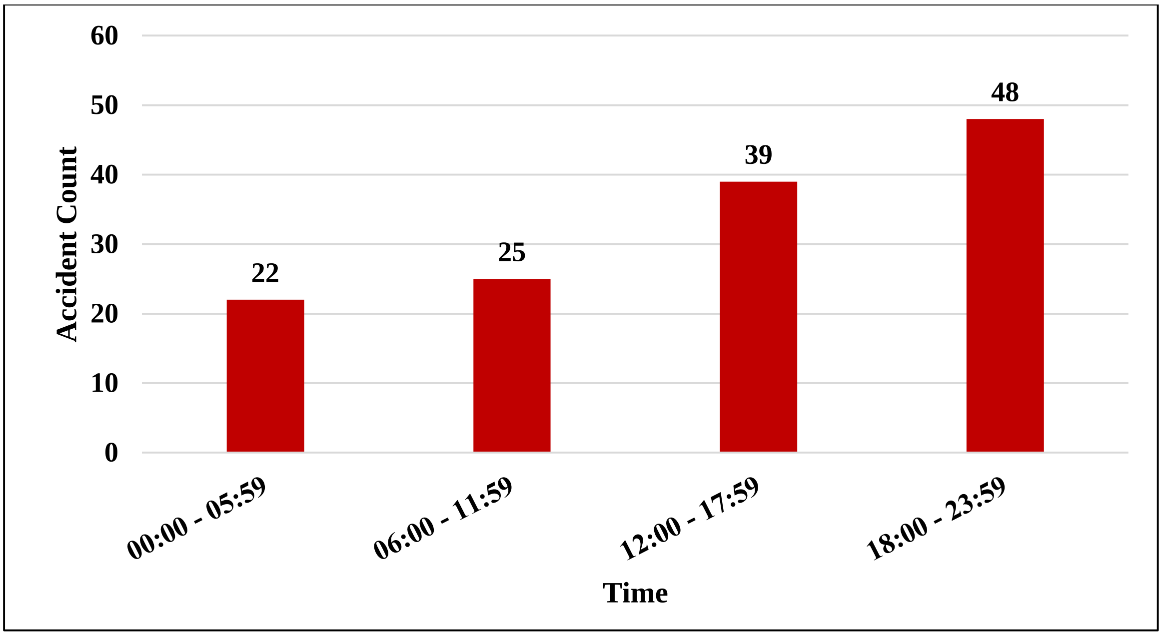
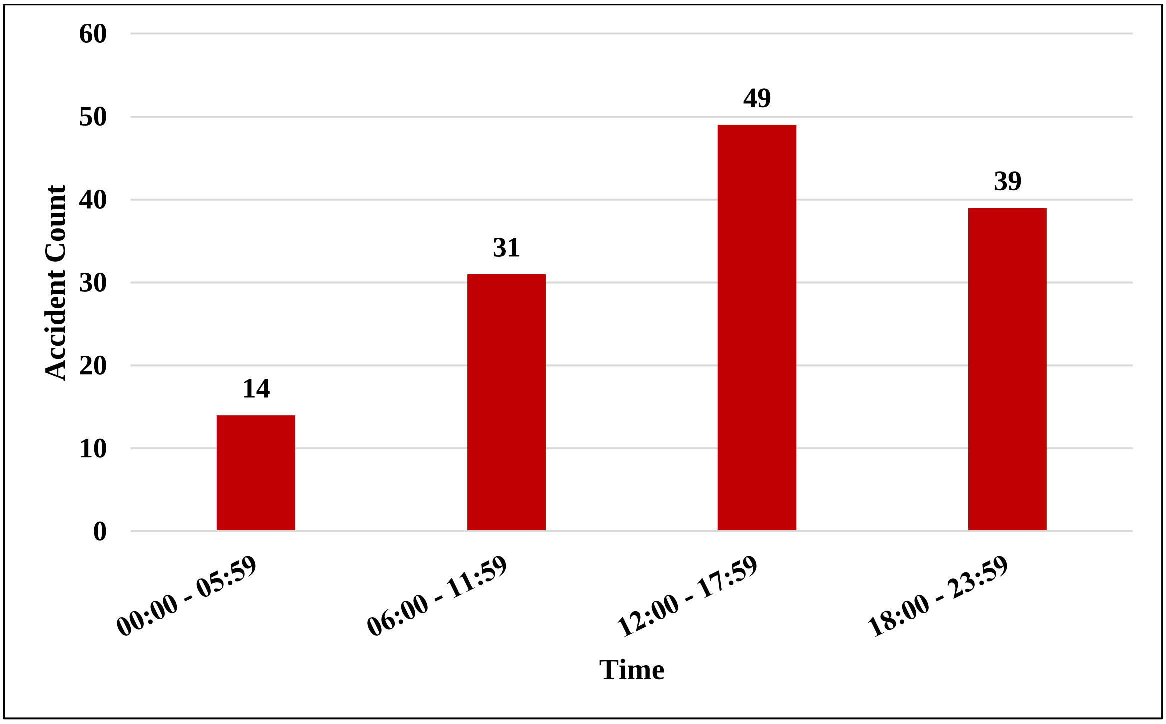
APPENDICES

Appendix 4.1 Fatal Accidents by Time

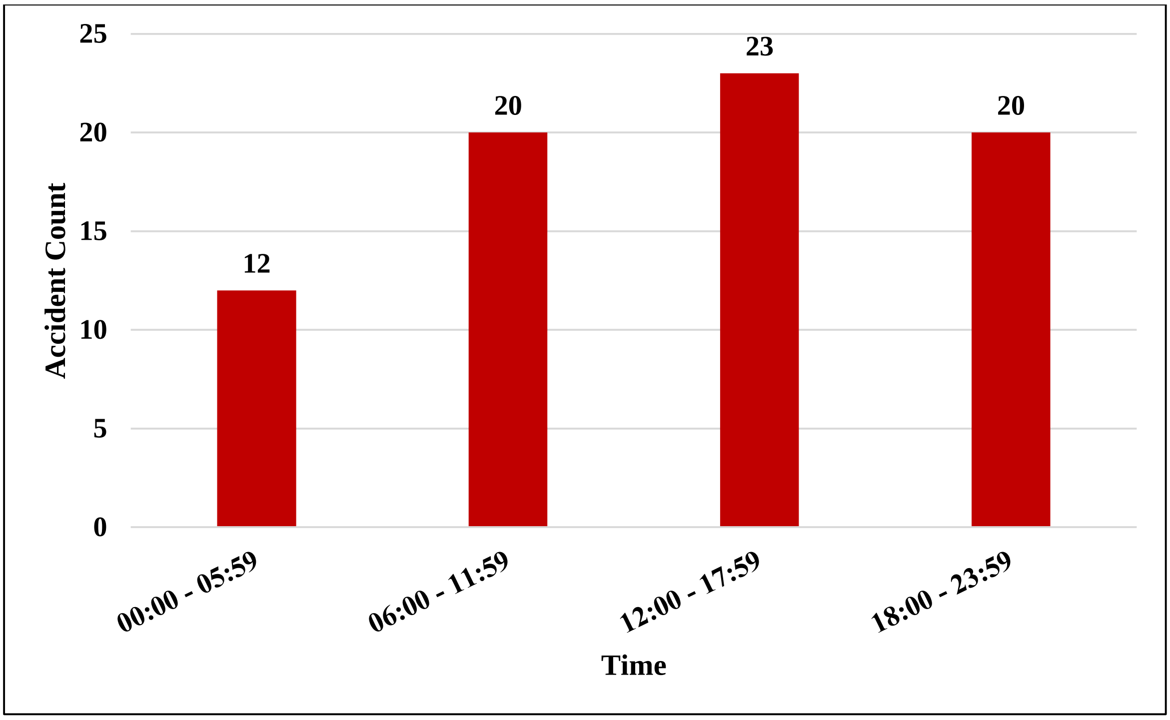
Appendix 4.1a Fatal Accidents by Time in 2011



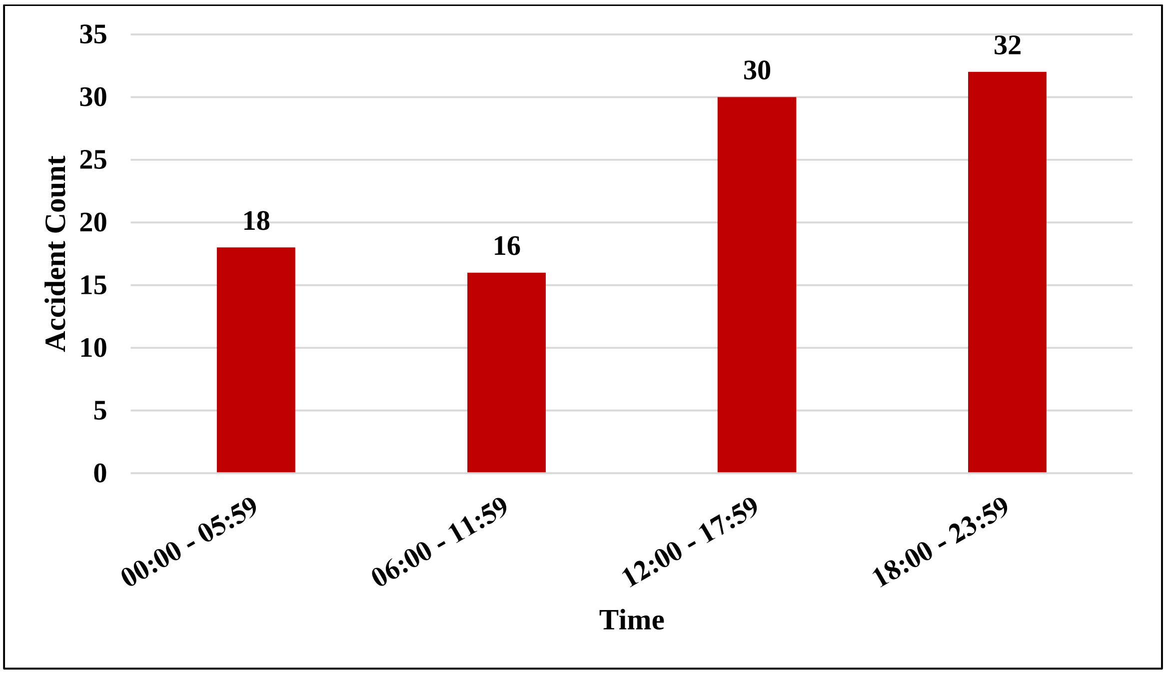
Appendix 4.1b Fatal Accidents by Time in 2012



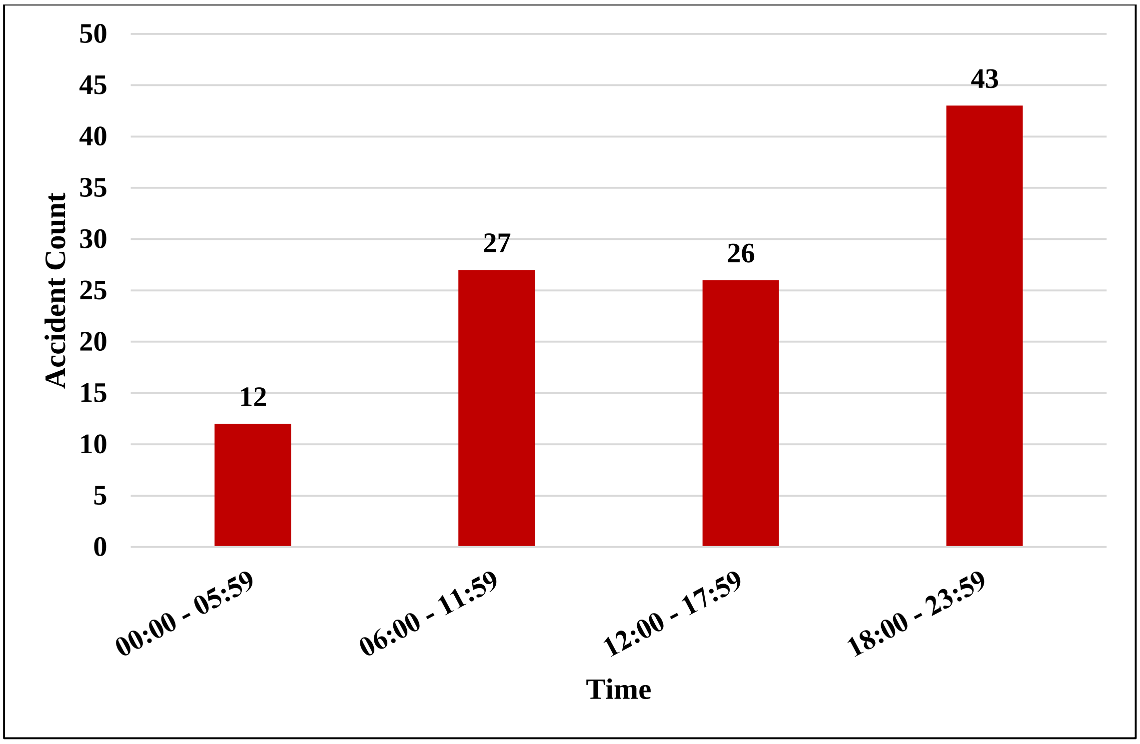
Appendix 4.1c Fatal Accidents by Time in 2013



Appendix 4.1d Fatal Accidents by Time in 2014

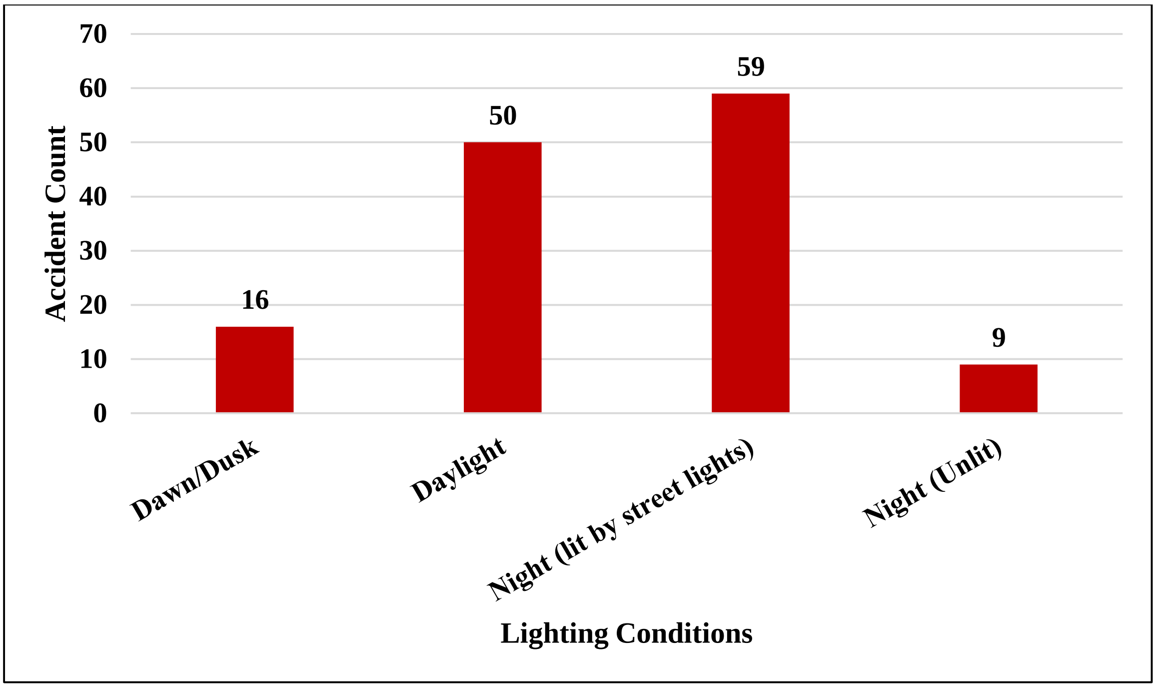


Appendix 4.1e Fatal Accidents by Time in 2015

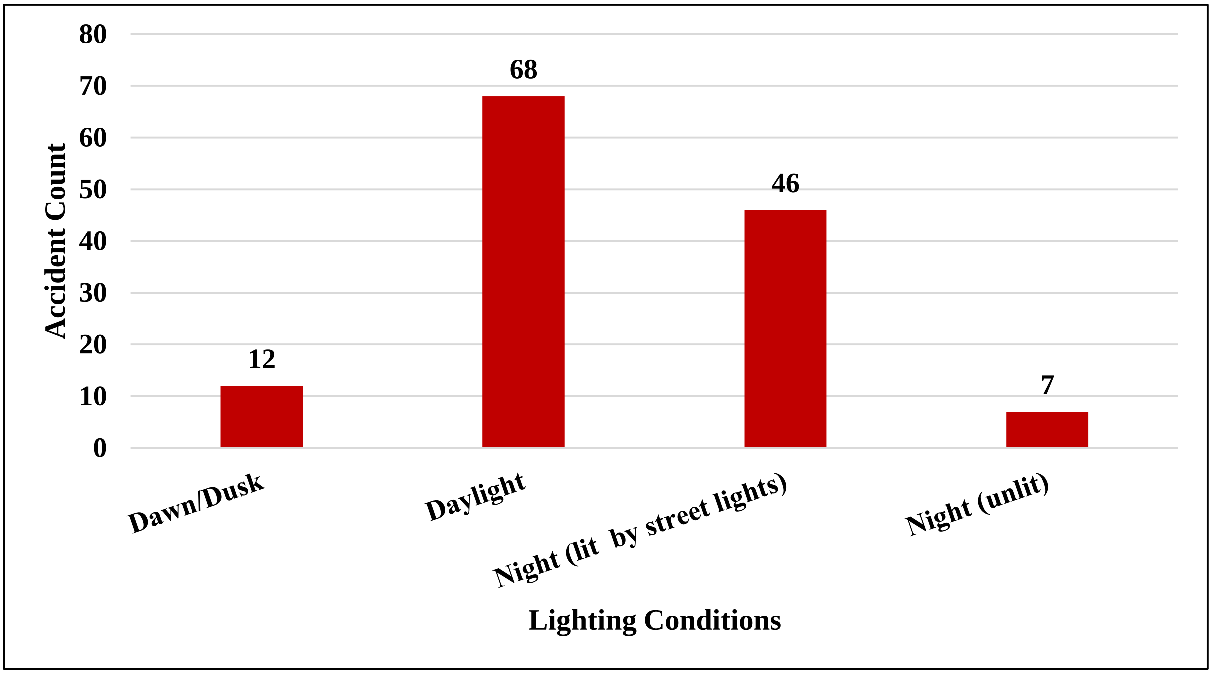


Appendix 4.2 Fatal Accidents by Lighting Conditions

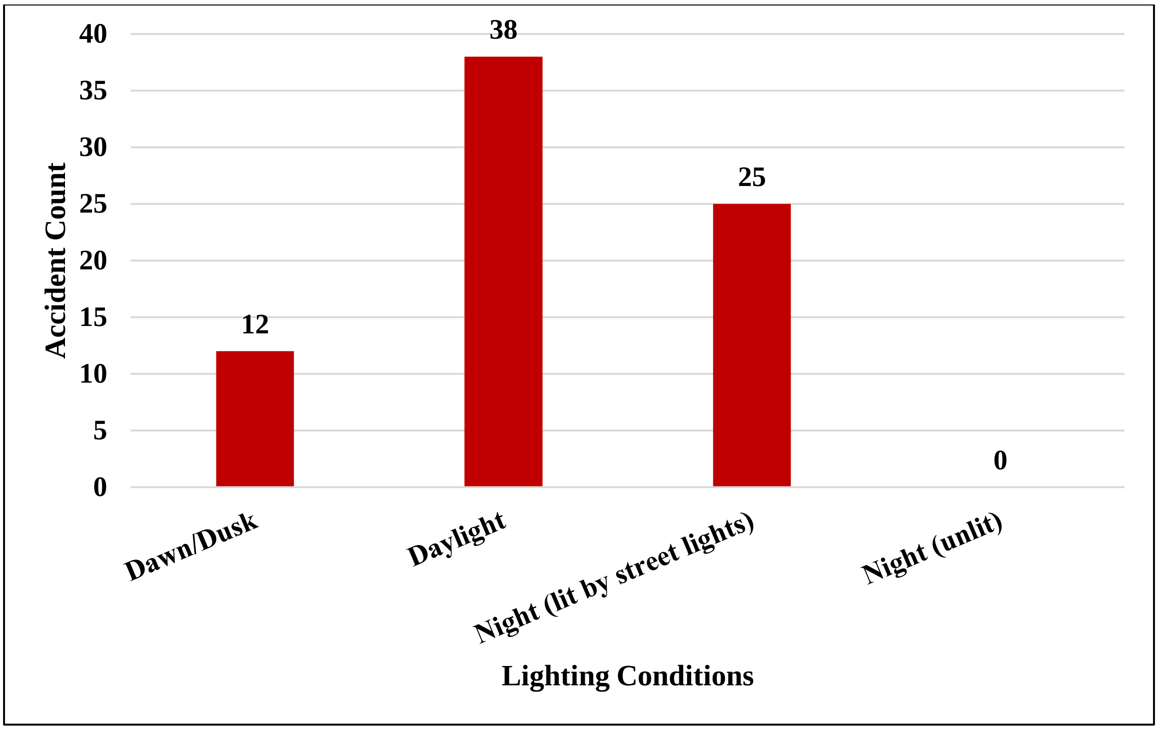
Appendix 4.2a Fatal Accidents by Lighting Conditions in 2011



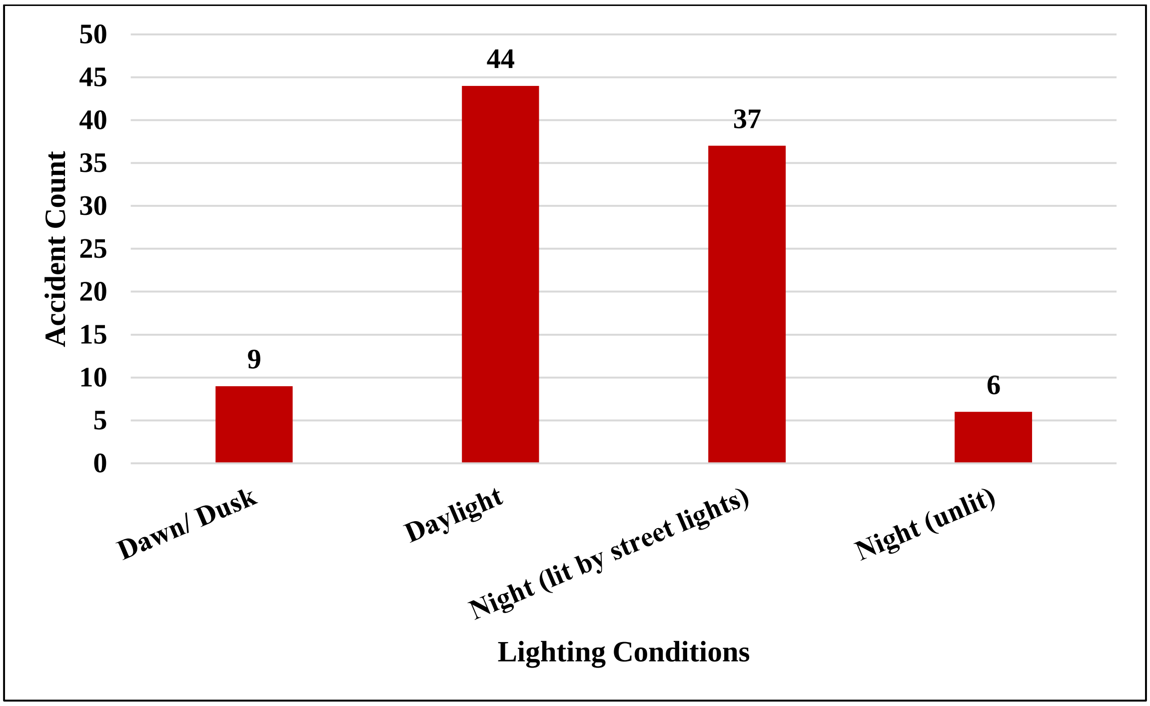
Appendix 4.2b Fatal Accidents by Lighting Conditions in 2012



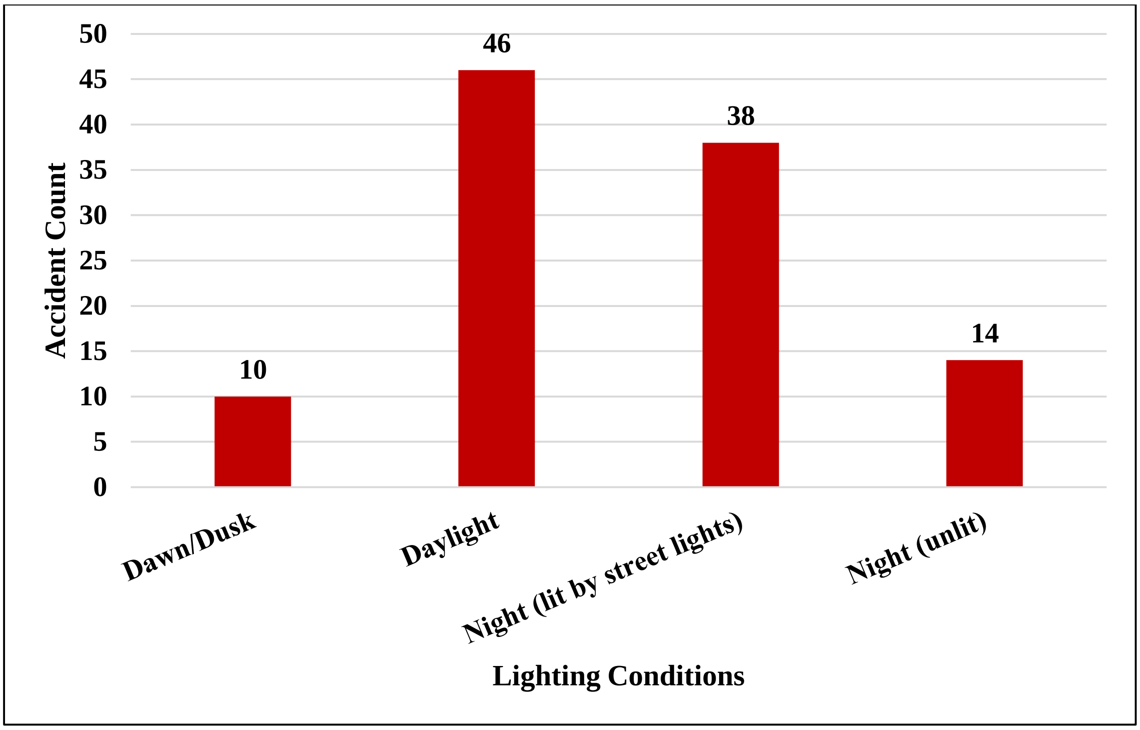
Appendix 4.2c Fatal Accidents by Lighting Conditions in 2013



Appendix 4.2.d Fatal Accidents by Lighting Conditions in 2014

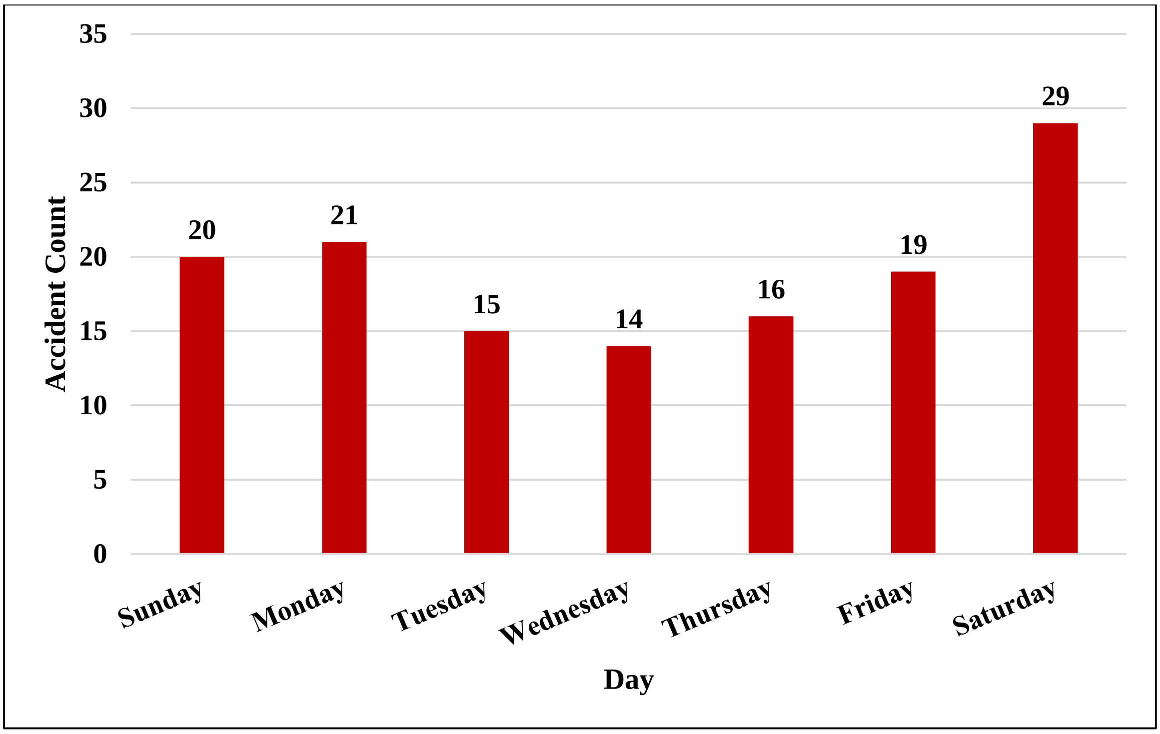


Appendix 4.2e Fatal Accidents by Lighting Conditions in 2015

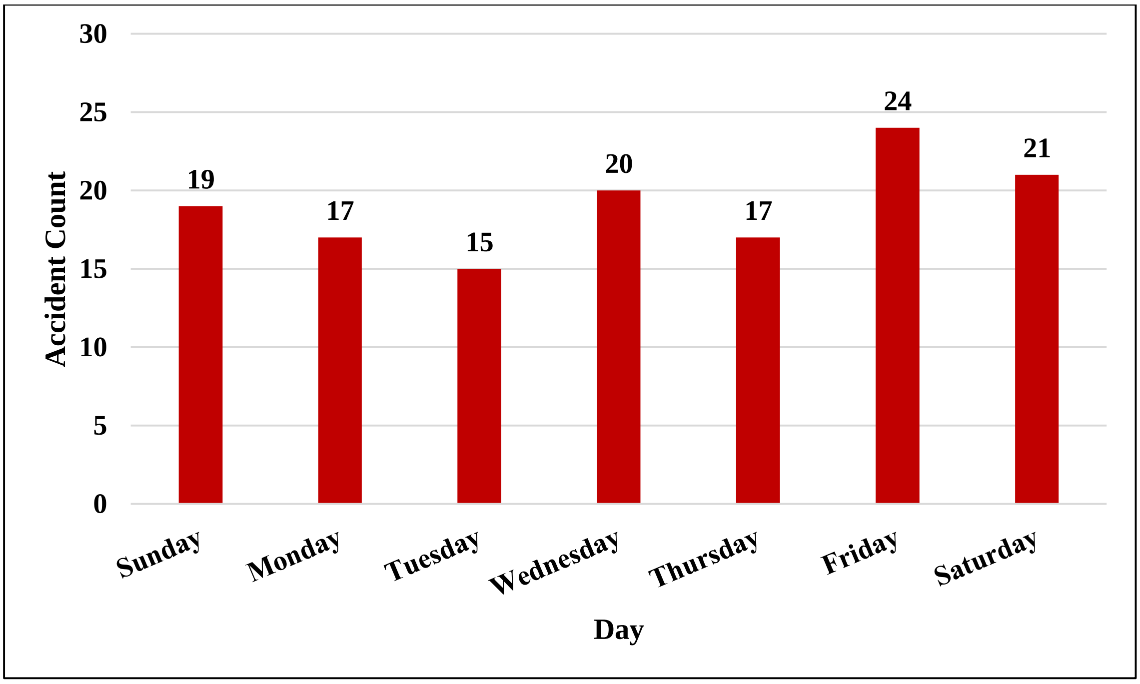


Appendix 4.3 Fatal Accidents by Day

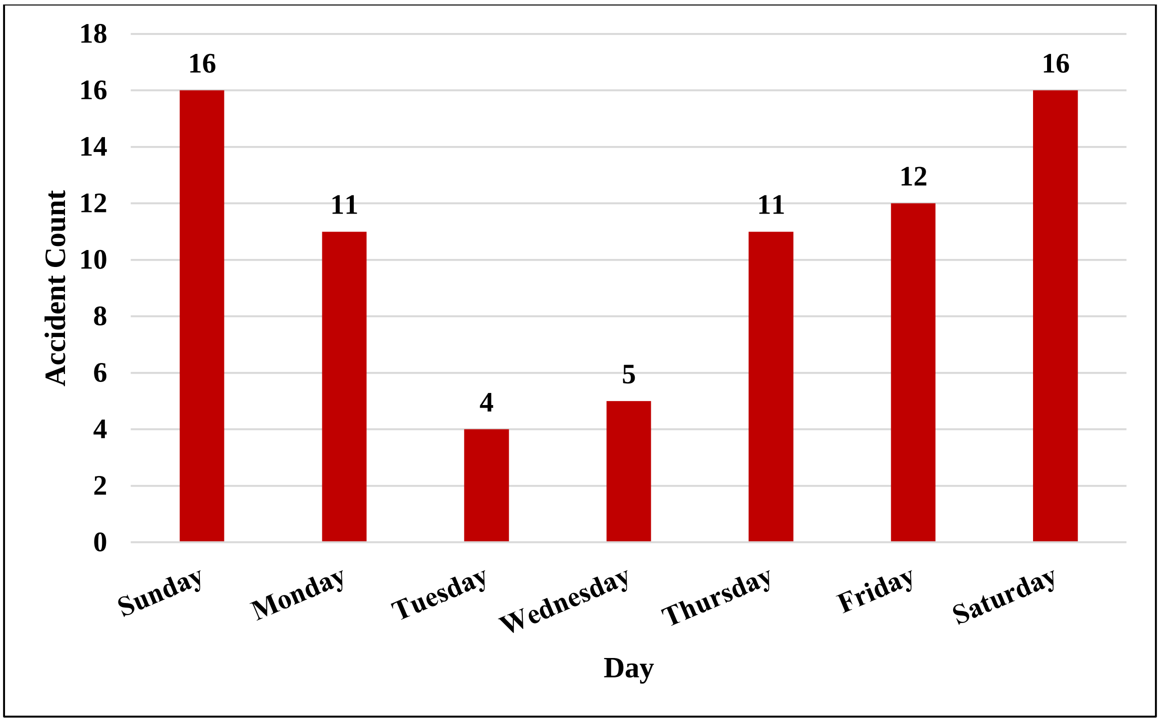
Appendix 4.3a Fatal Accidents by Day in 2011



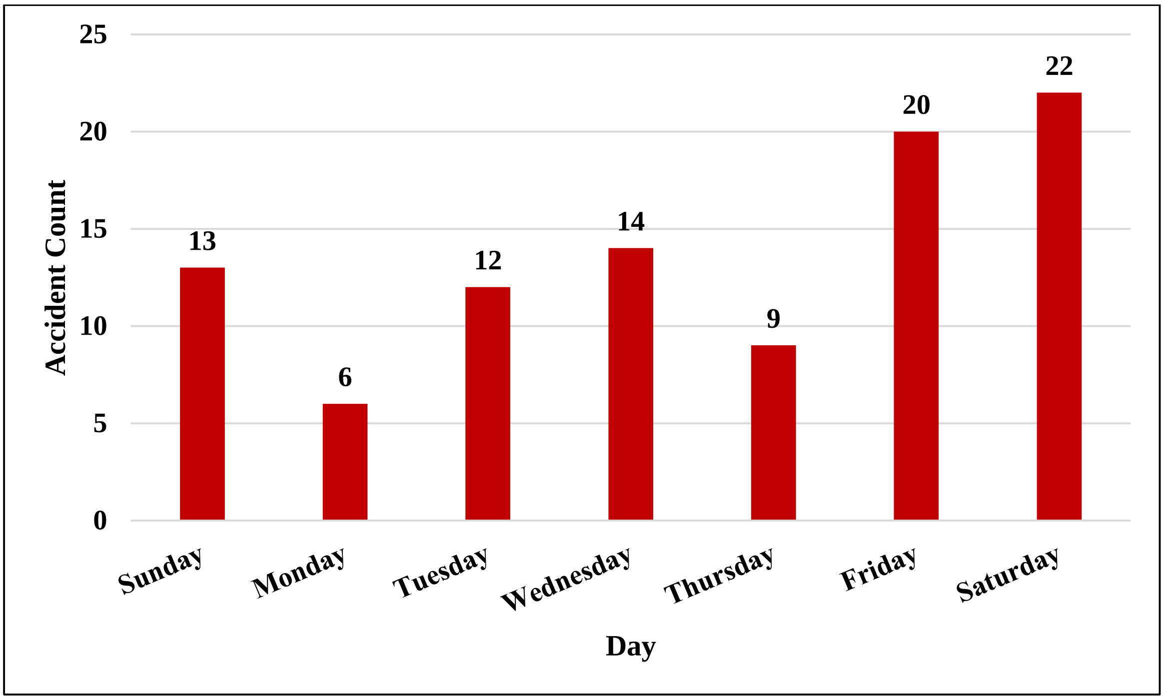
Appendix 4.3b Fatal Accidents by Day in 2012



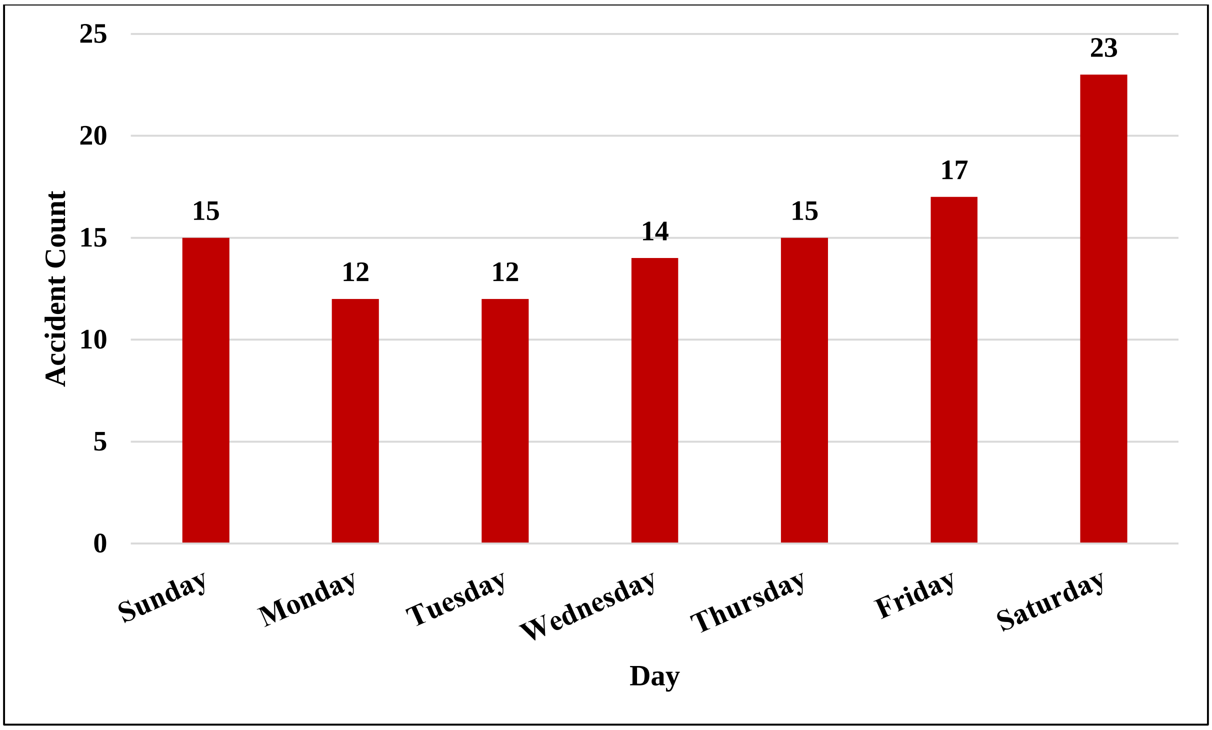
Appendix 4.3c Fatal Accidents by Day in 2013



Appendix 4.3d Fatal Accidents by Day in 2014

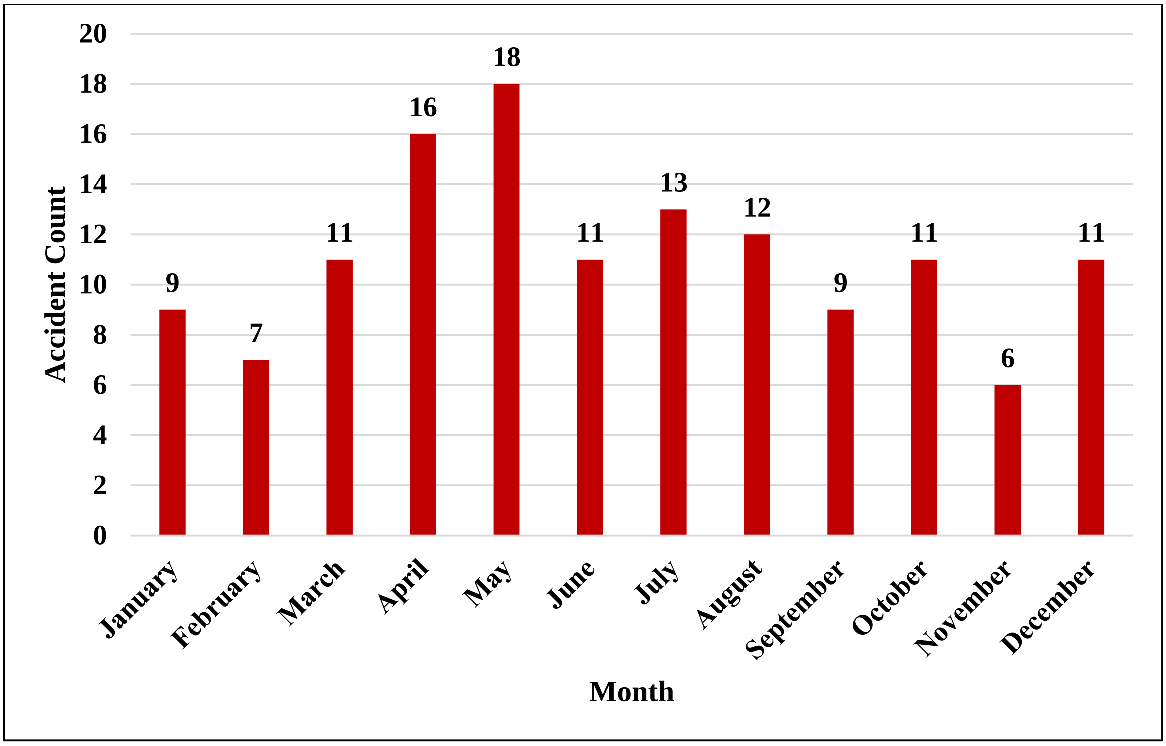


Appendix 4.3e Fatal Accidents by Day in 2015

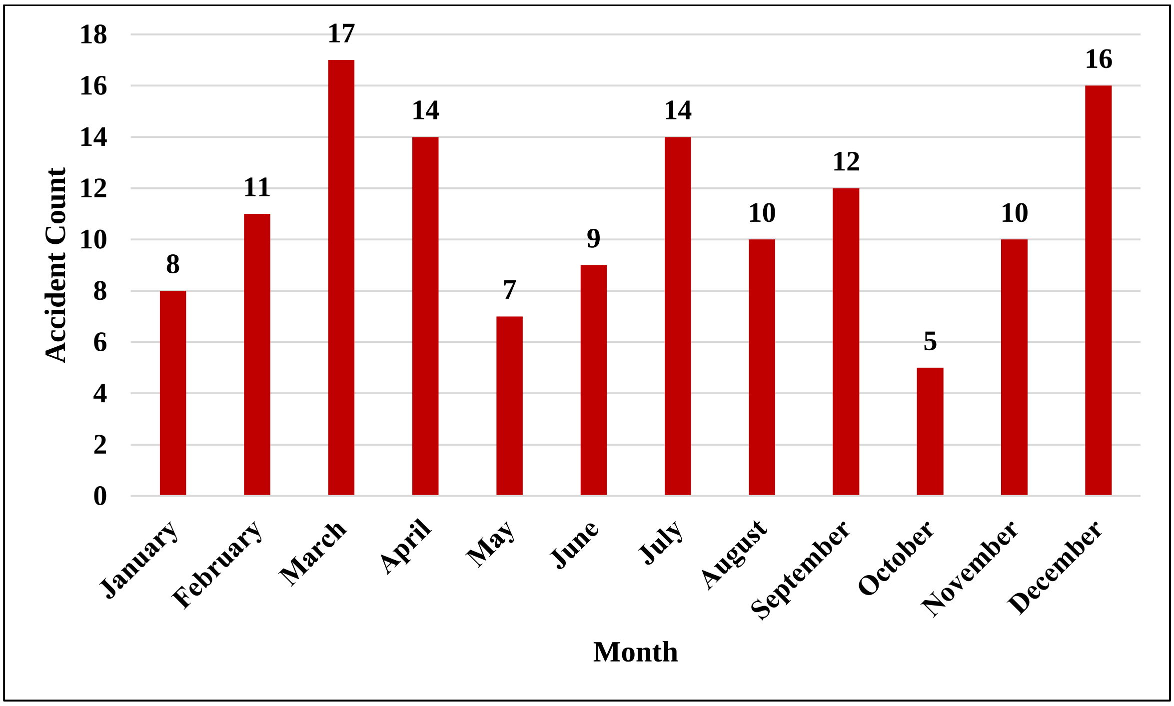


Appendix 4.4 Fatal Accidents by Month

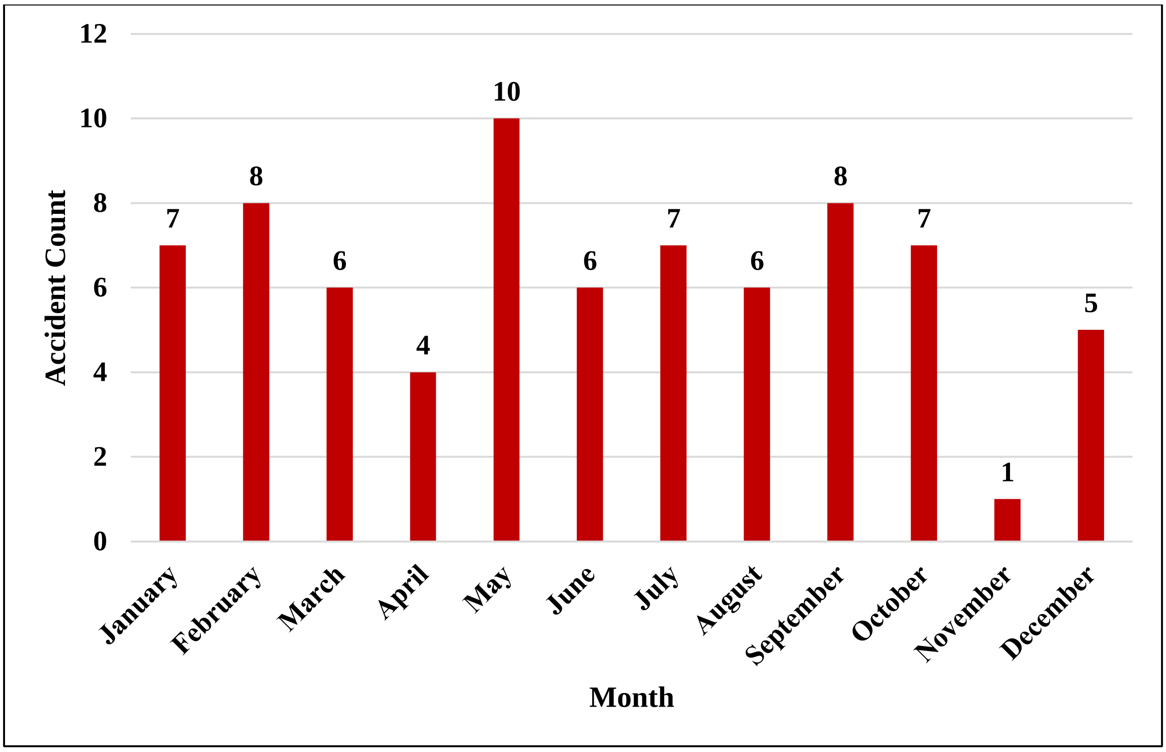
Appendix 4.4a Fatal Accidents by Month in 2011



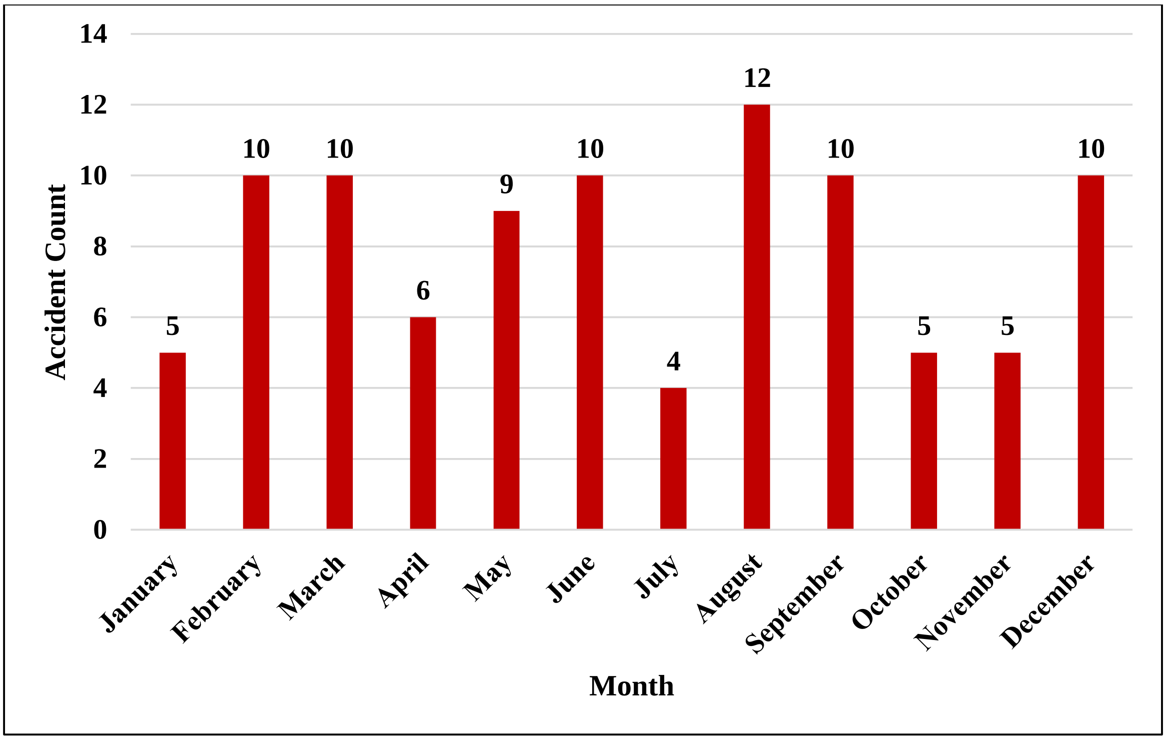
Appendix 4.4b Fatal Accidents by Month in 2012



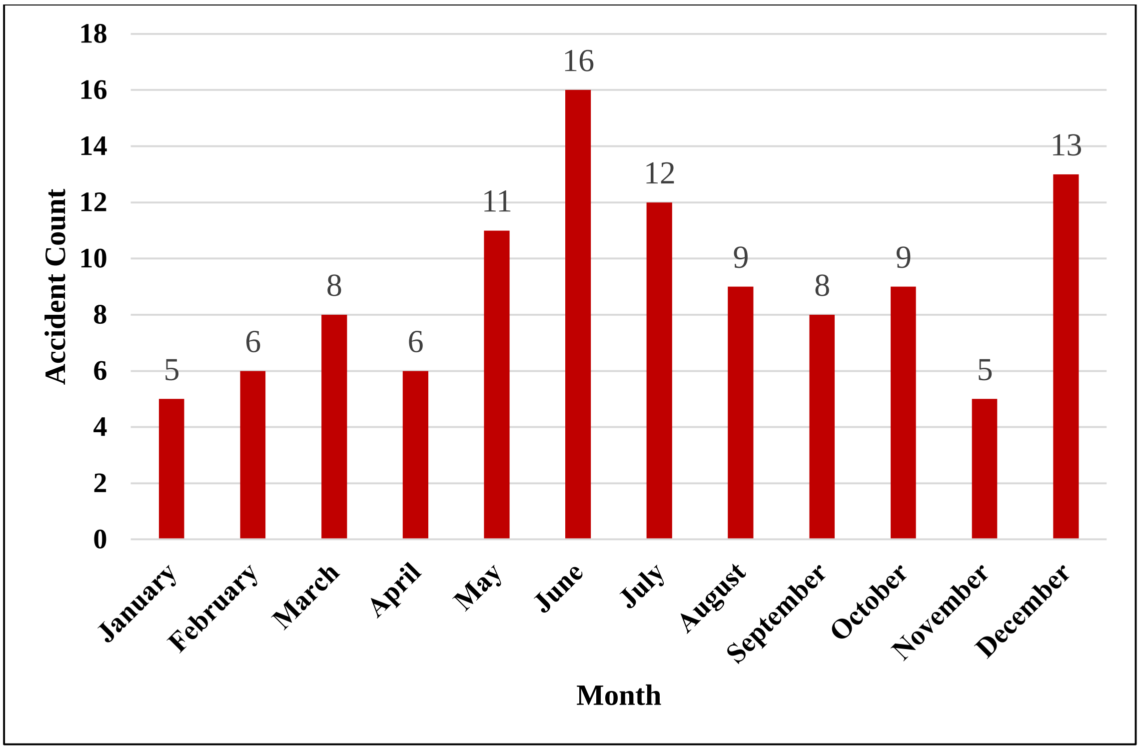
Appendix 4.4c Fatal Accidents by Month in 2013



Appendix 4.4d Fatal Accidents by Month in 2014

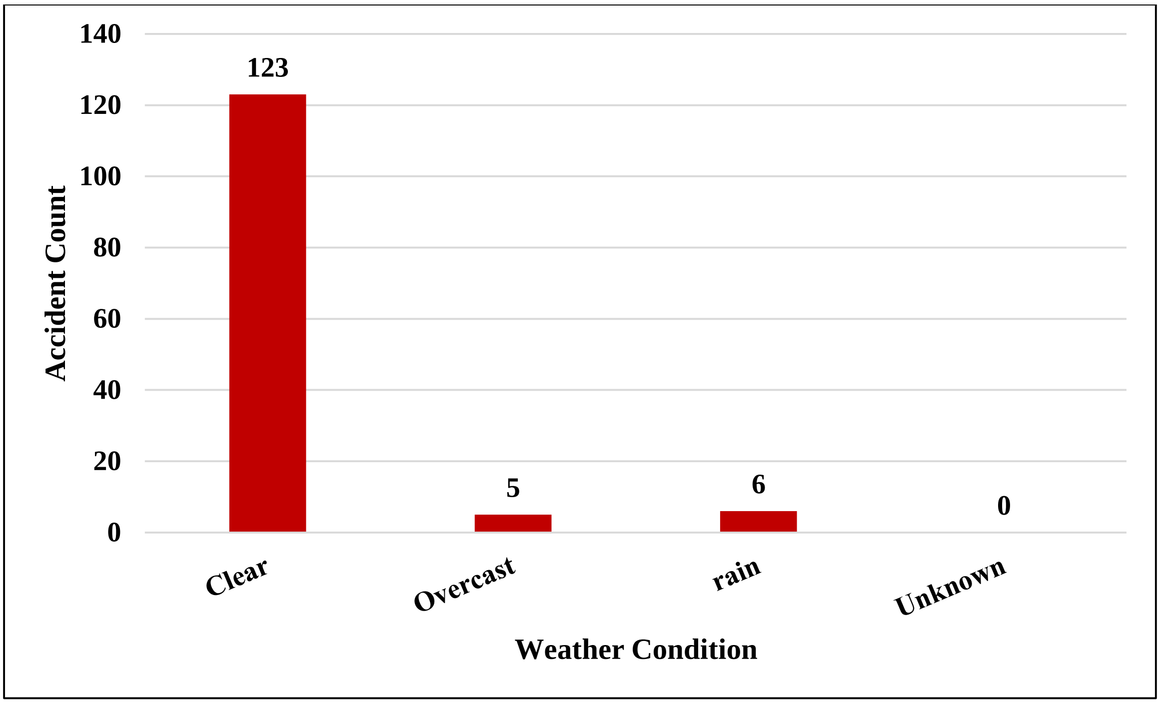


Appendix 4.4e Fatal Accidents by Month in 2015

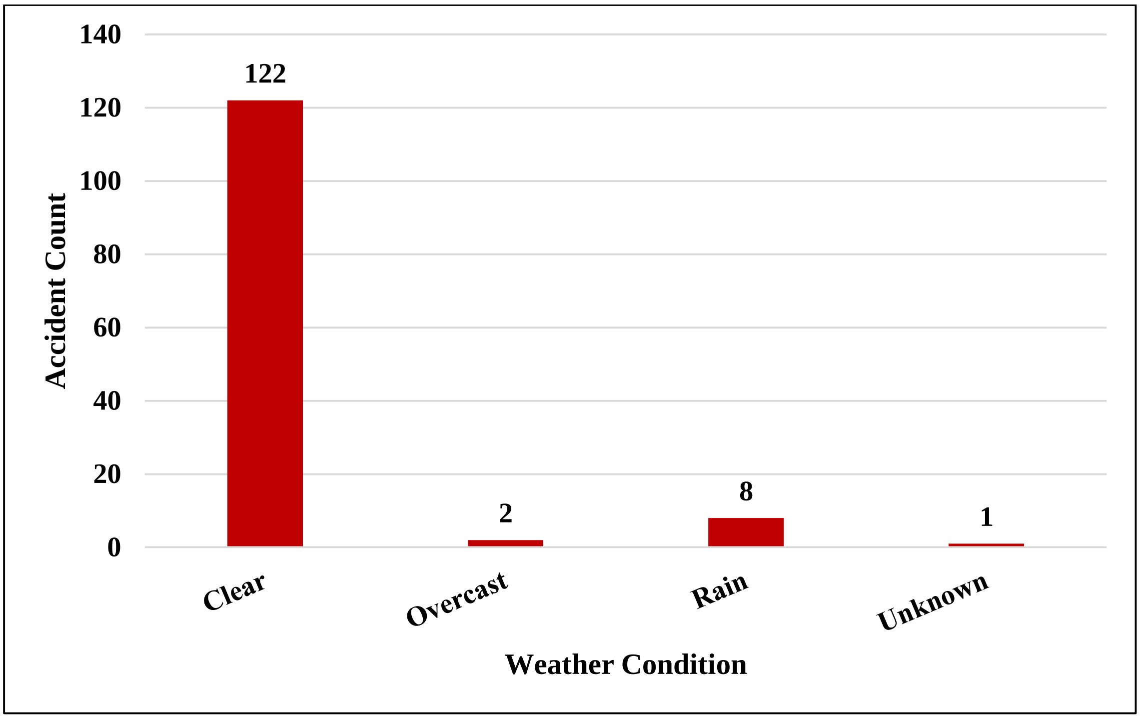


Appendix 4.5 Fatal Accidents by Weather Conditions

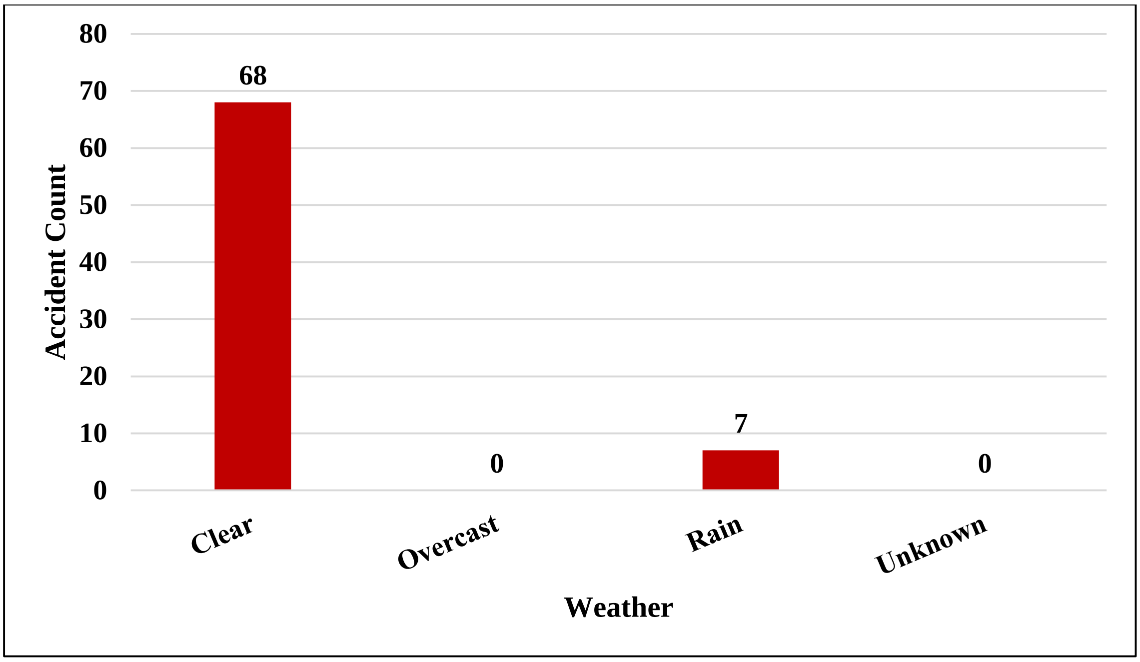
Appendix 4.5a Fatal Accidents by Weather Conditions in 2011



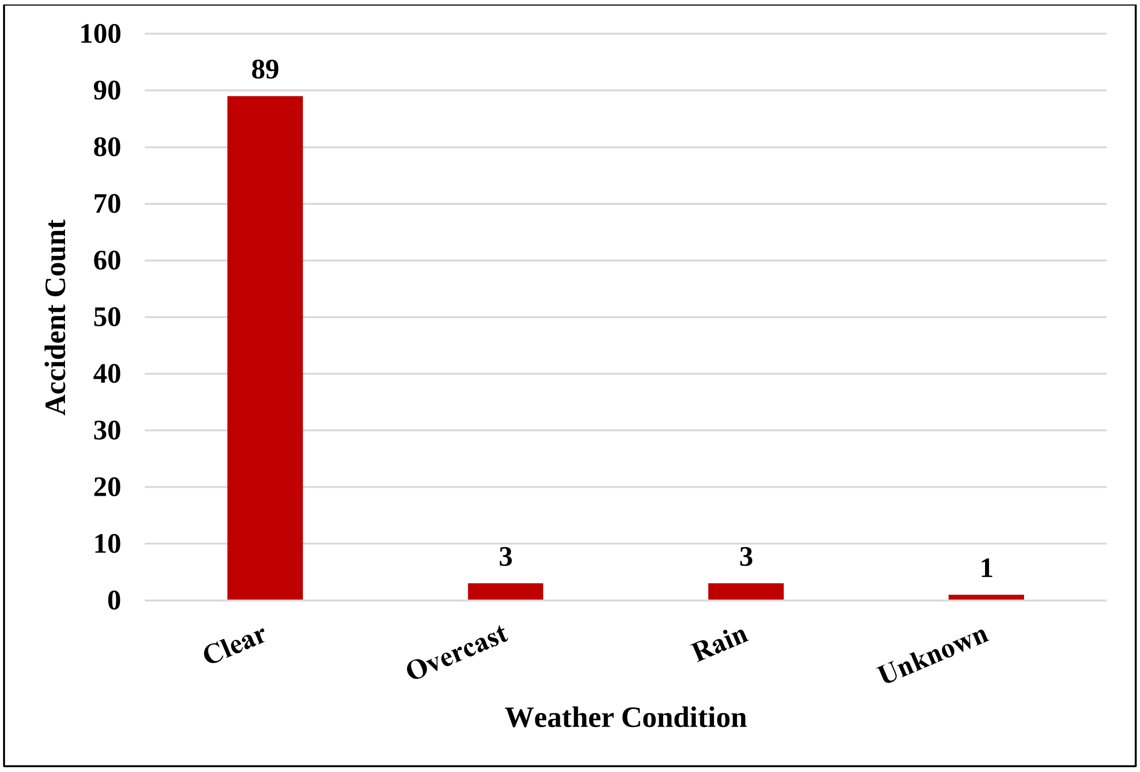
Appendix 4.5b Fatal Accidents by Weather Conditions in 2012



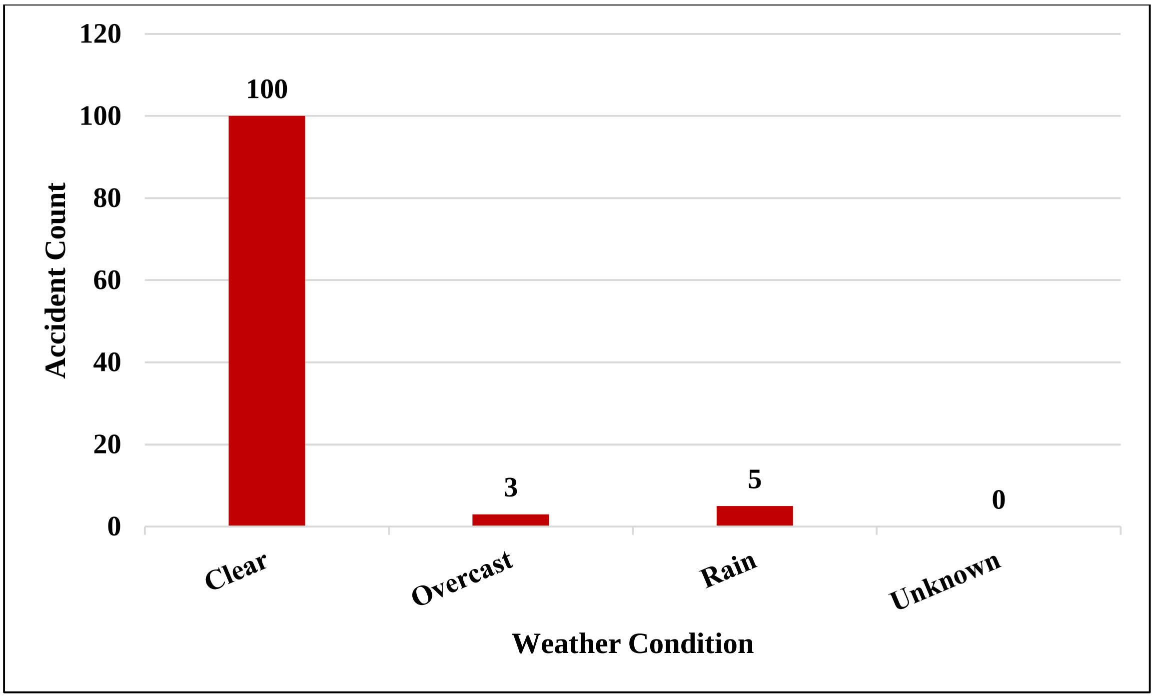
Appendix 4.5c Fatal Accidents by Weather Conditions in 2013



Appendix 4.5d Fatal Accidents by Weather Conditions in 2014

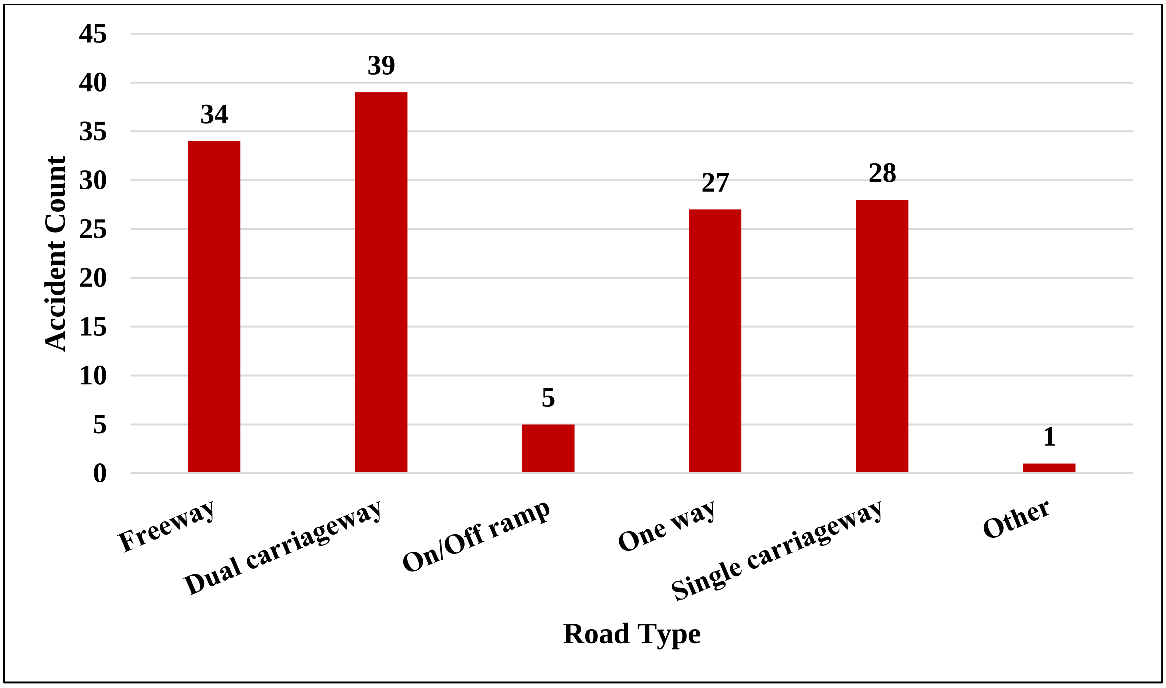


Appendix 4.5e Fatal Accidents by Weather Conditions in 2015

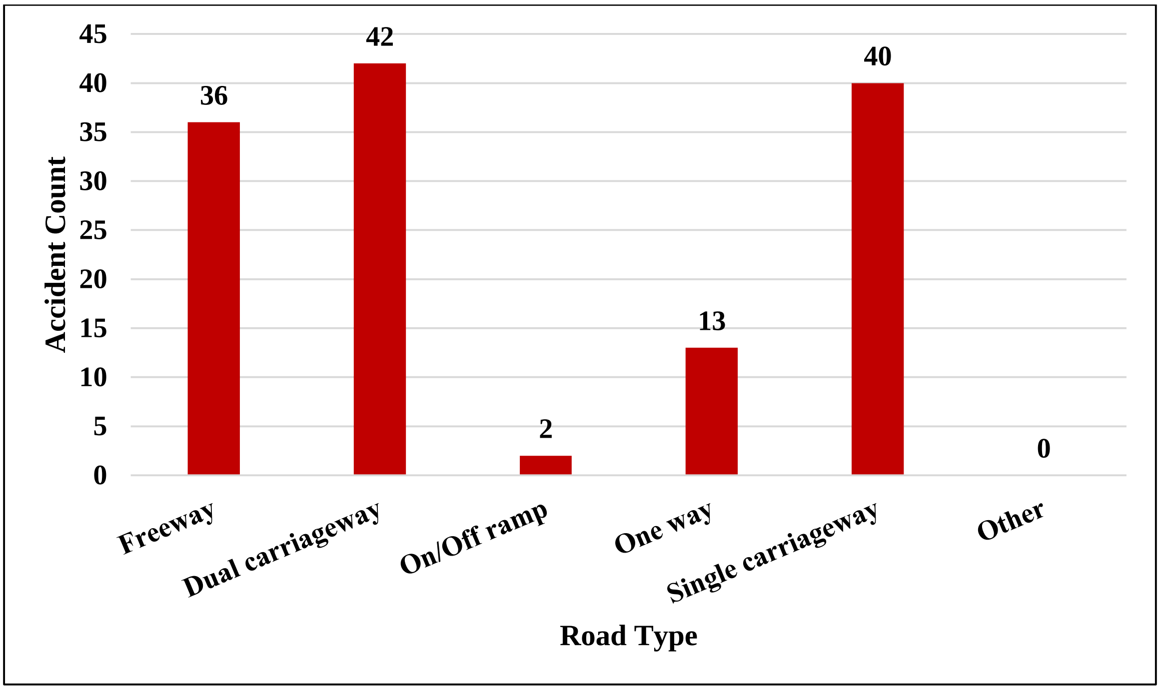


Appendix 4.6 Fatal Accidents by Road Type

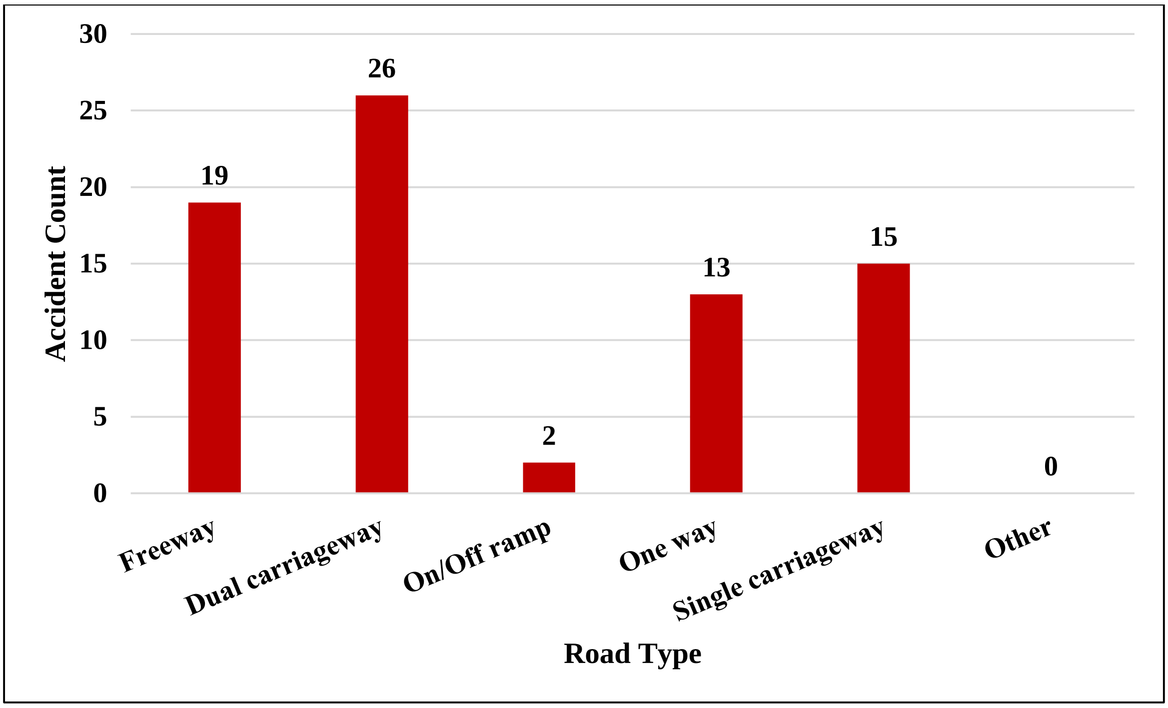
Appendix 4.6a Fatal Accidents by Road Type in 2011



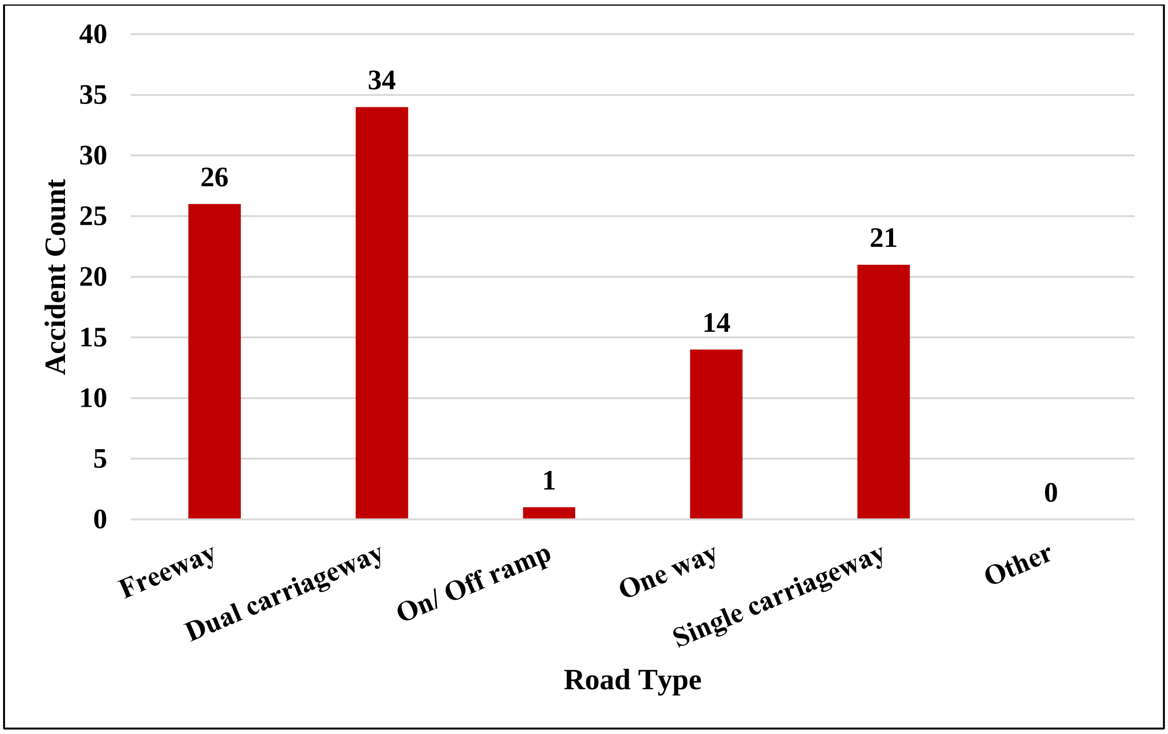
Appendix 4.6b Fatal Accidents by Road Type in 2012



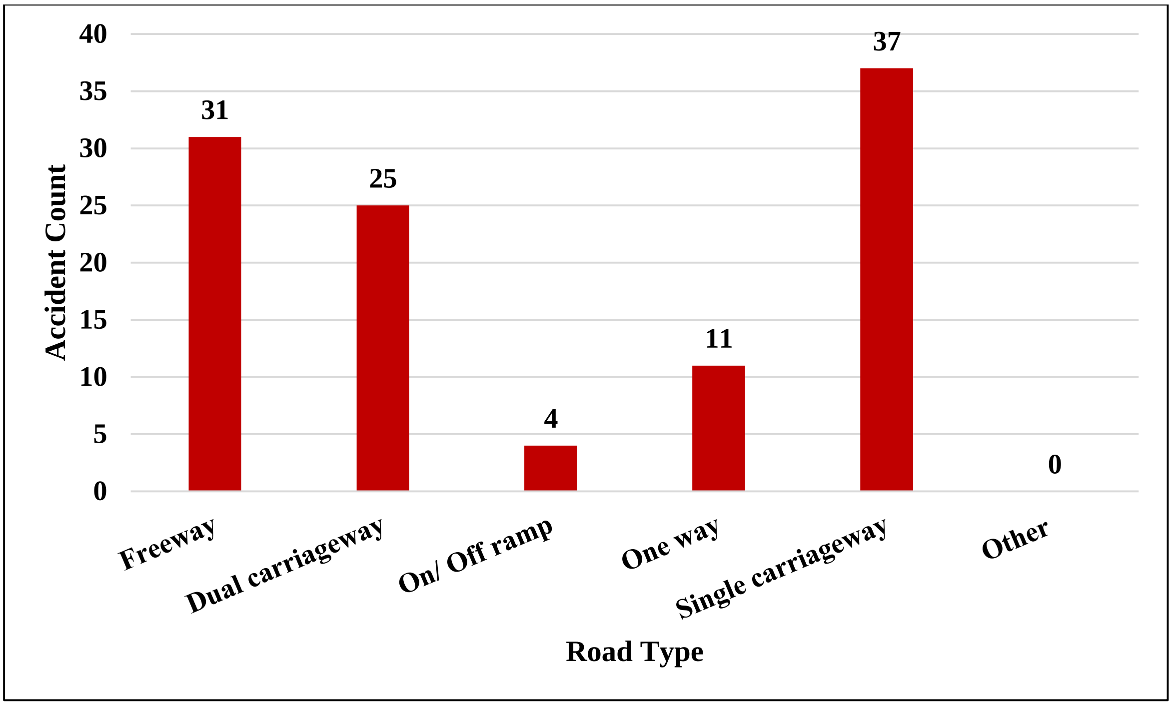
Appendix 4.6c Fatal Accidents by Road Type in 2013



Appendix 4.6d Fatal Accidents by Road Type in 2014

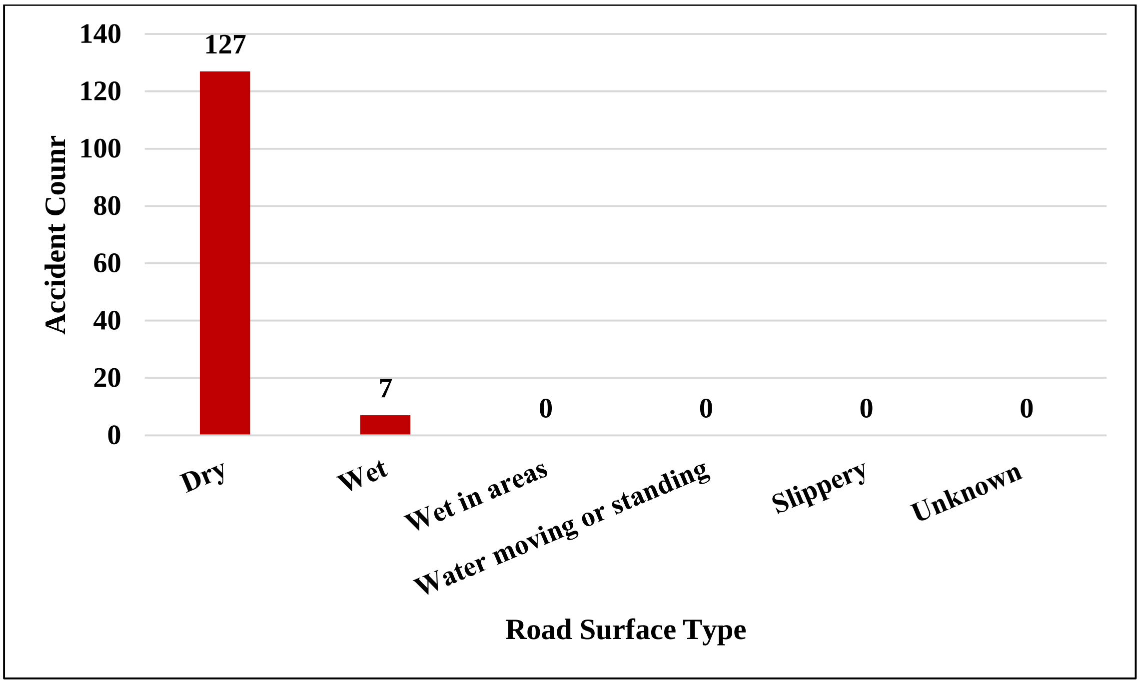


Appendix 4.6e Fatal Accidents by Road Type in 2015

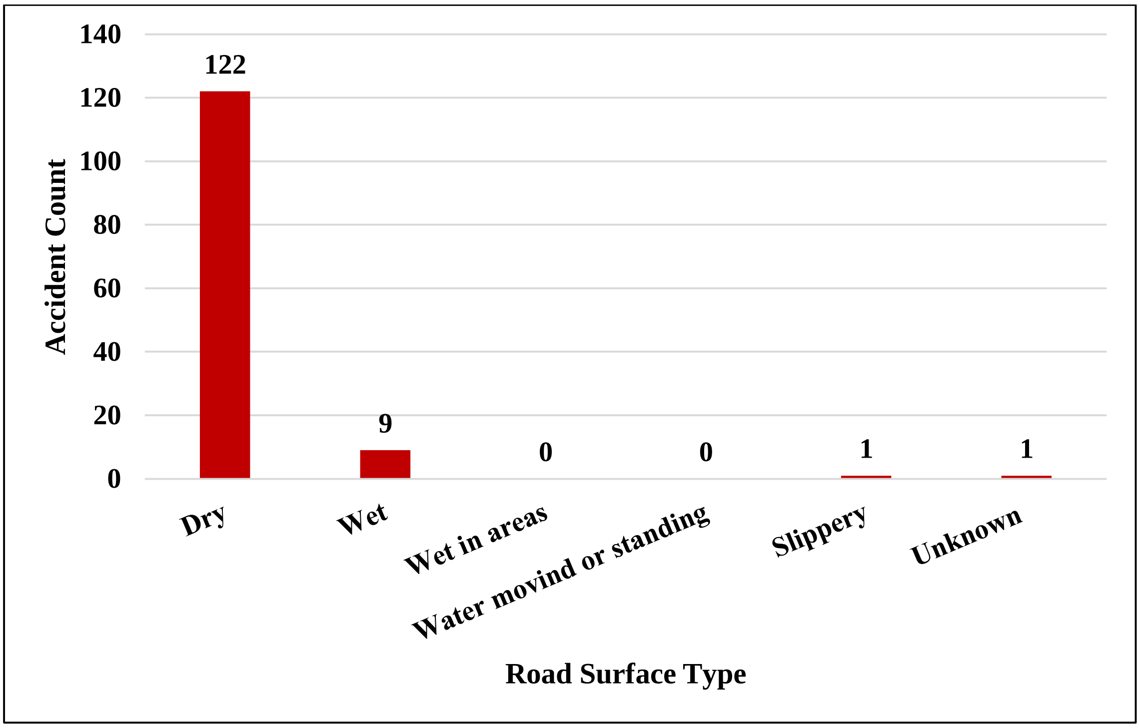


Appendix 4.7 Fatal Accidents by Road Surface Type

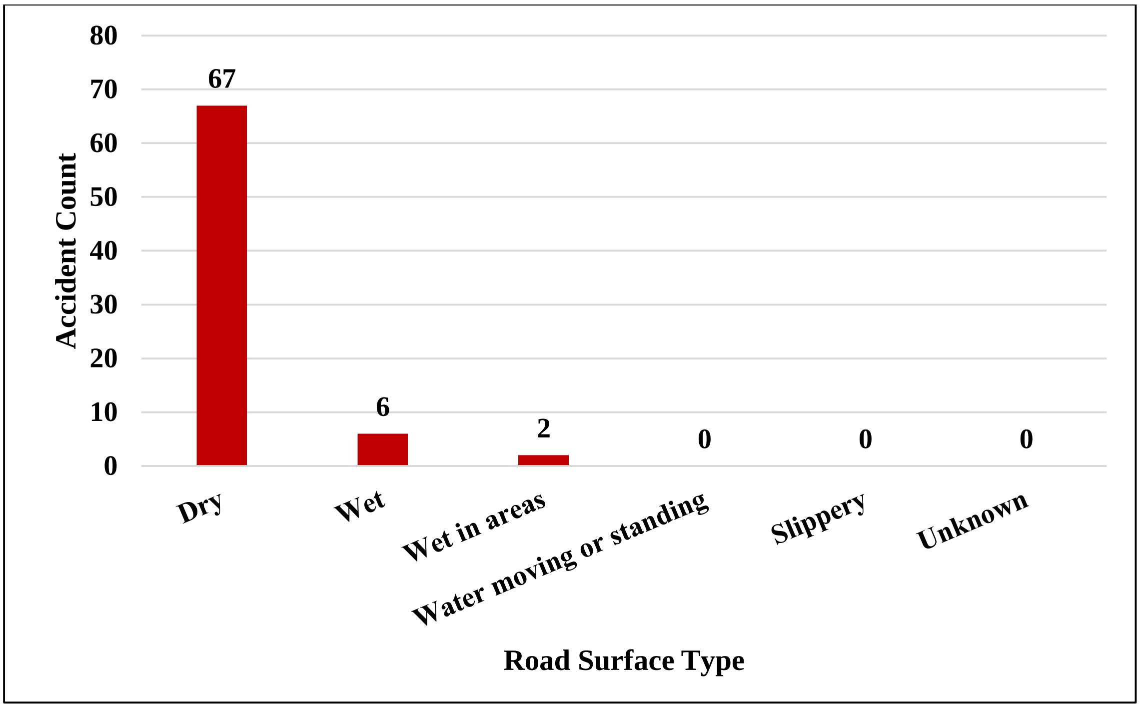
Appendix 4.7a Fatal Accidents by Road Surface Type in 2011



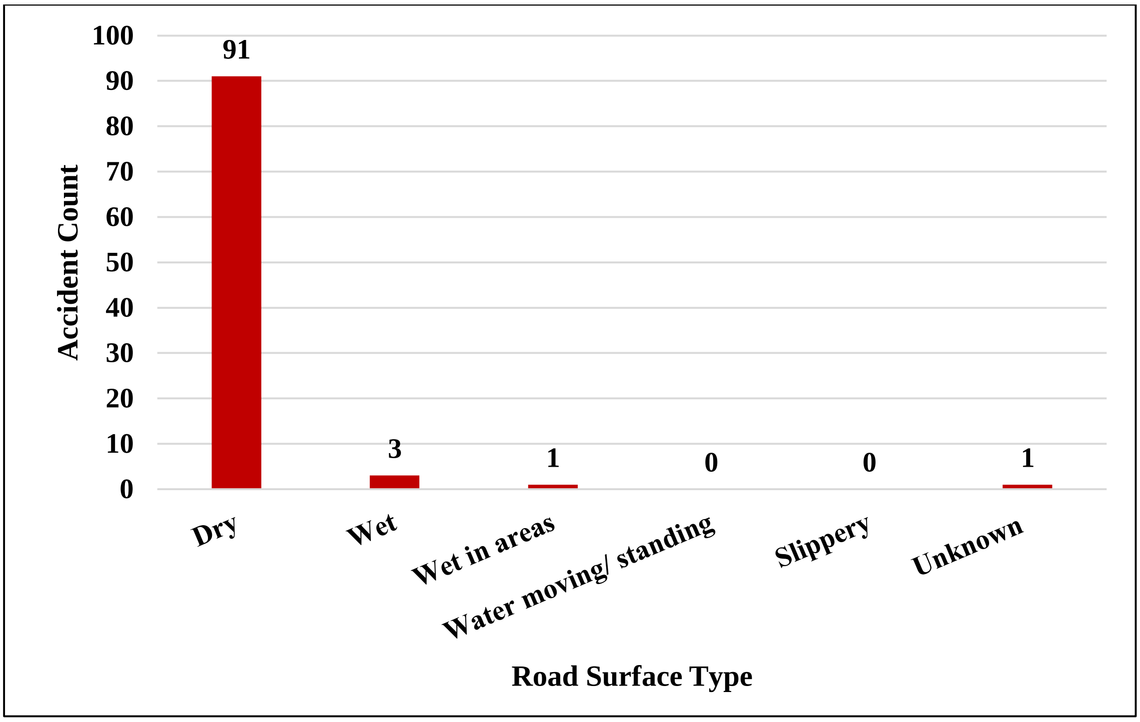
Appendix 4.7b Fatal Accidents by Road Surface Type in 2012



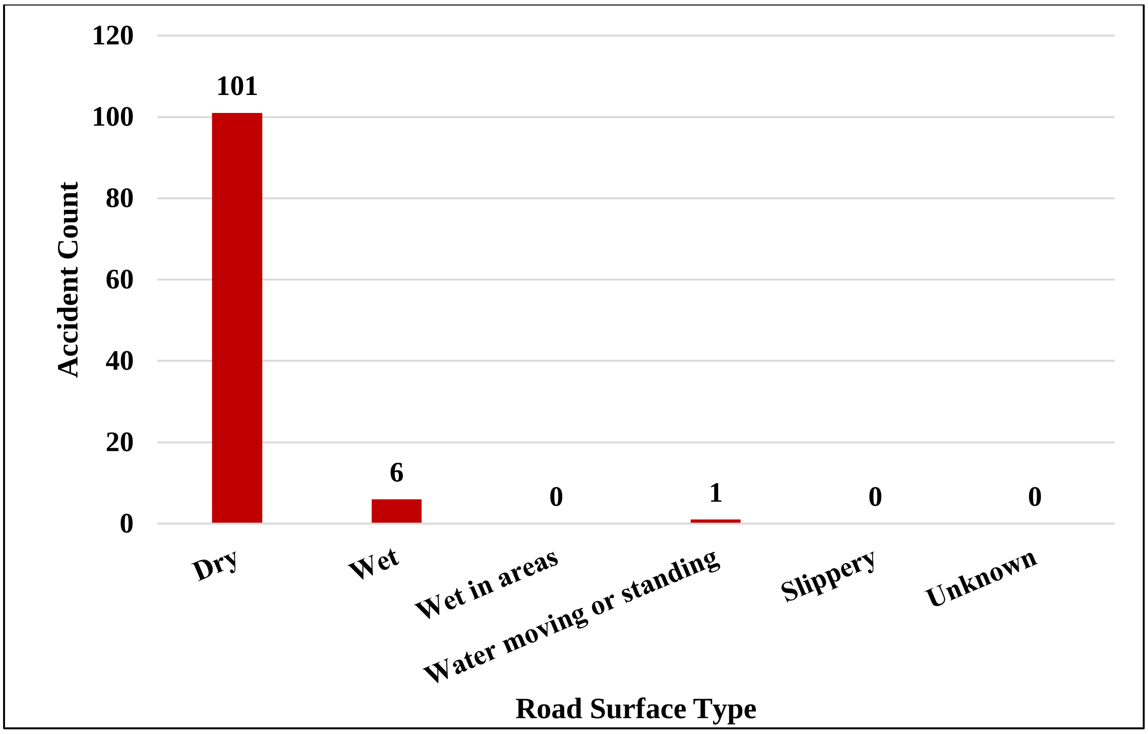
Appendix 4.7c Fatal Accidents by Road Surface Type in 2013



Appendix 4.7d Fatal Accidents by Road Surface Type in 2014

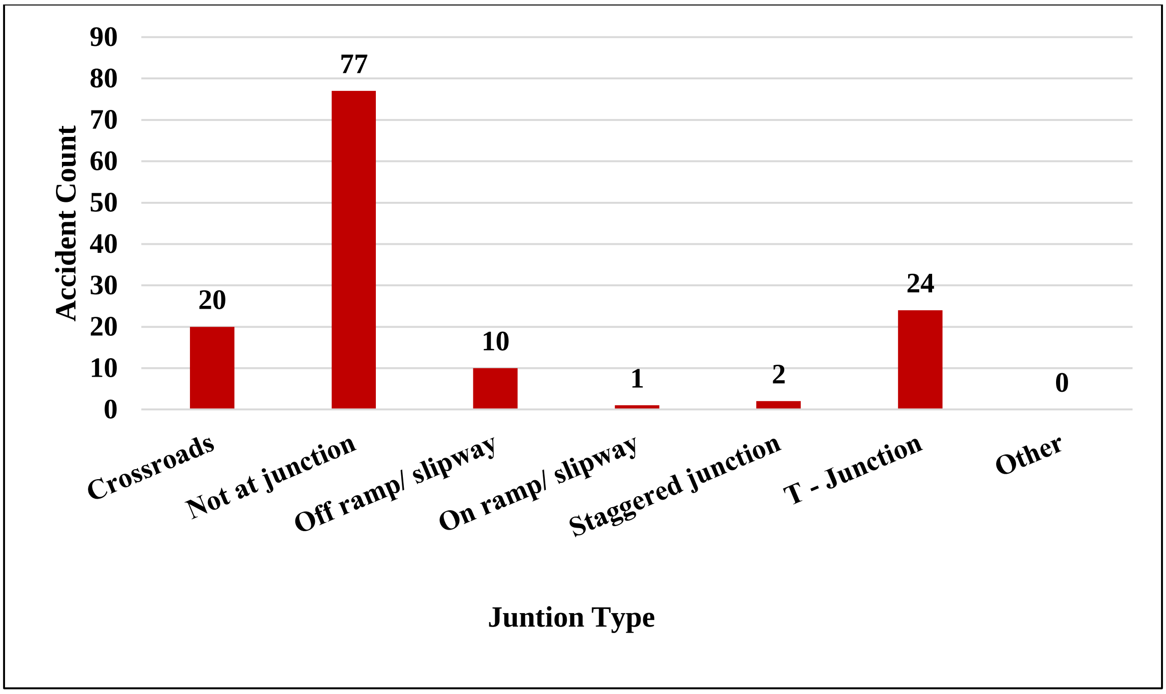


Appendix 4.7e Fatal Accidents by Road Surface Type in 2015

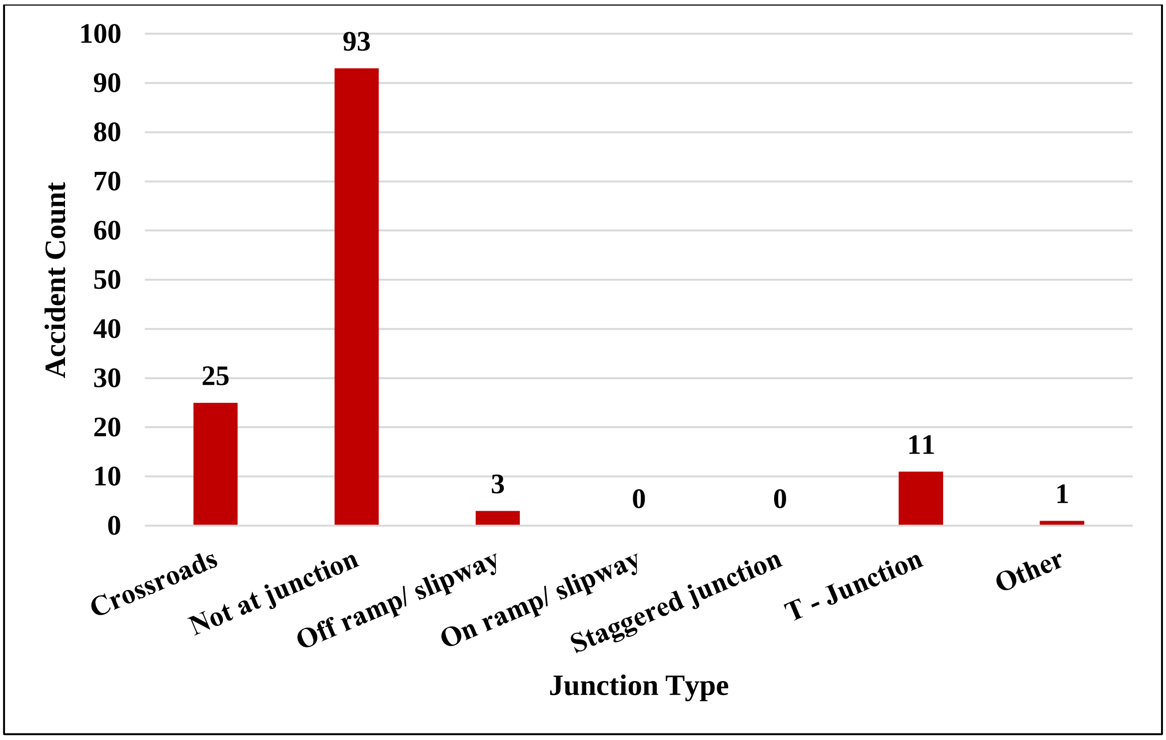


Appendix 4.8 Fatal Accidents by Junction Type

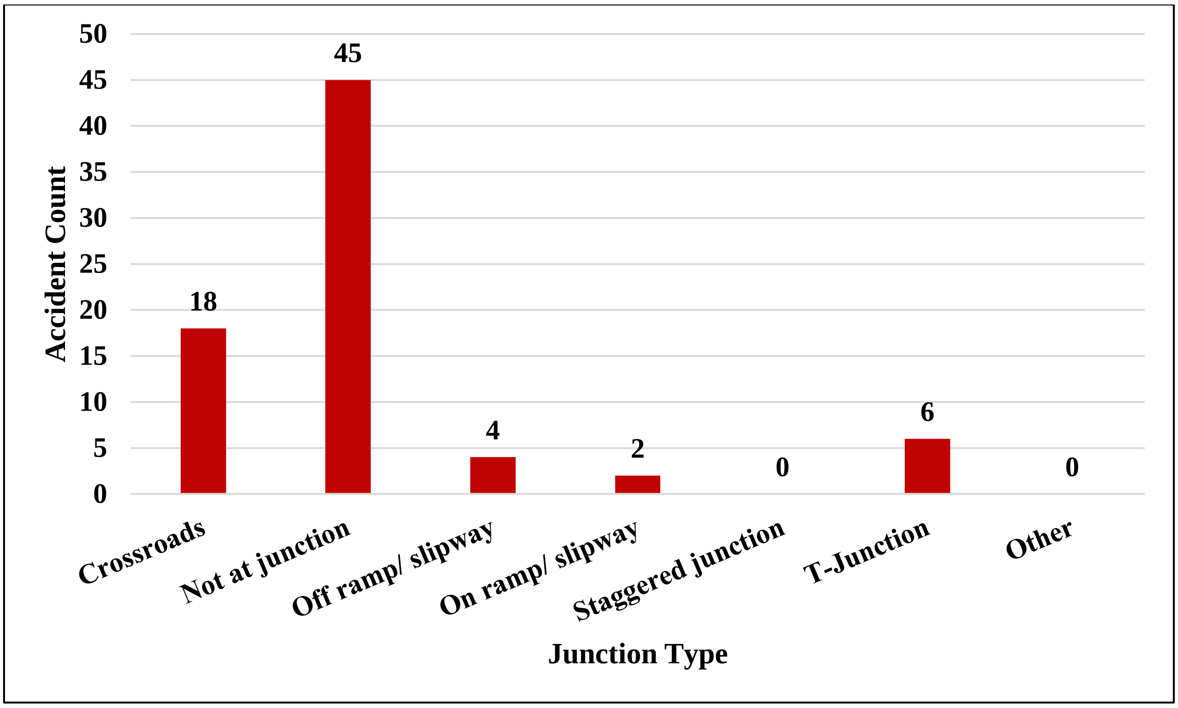
Appendix 4.8a Fatal Accidents by Junction Type in 2011



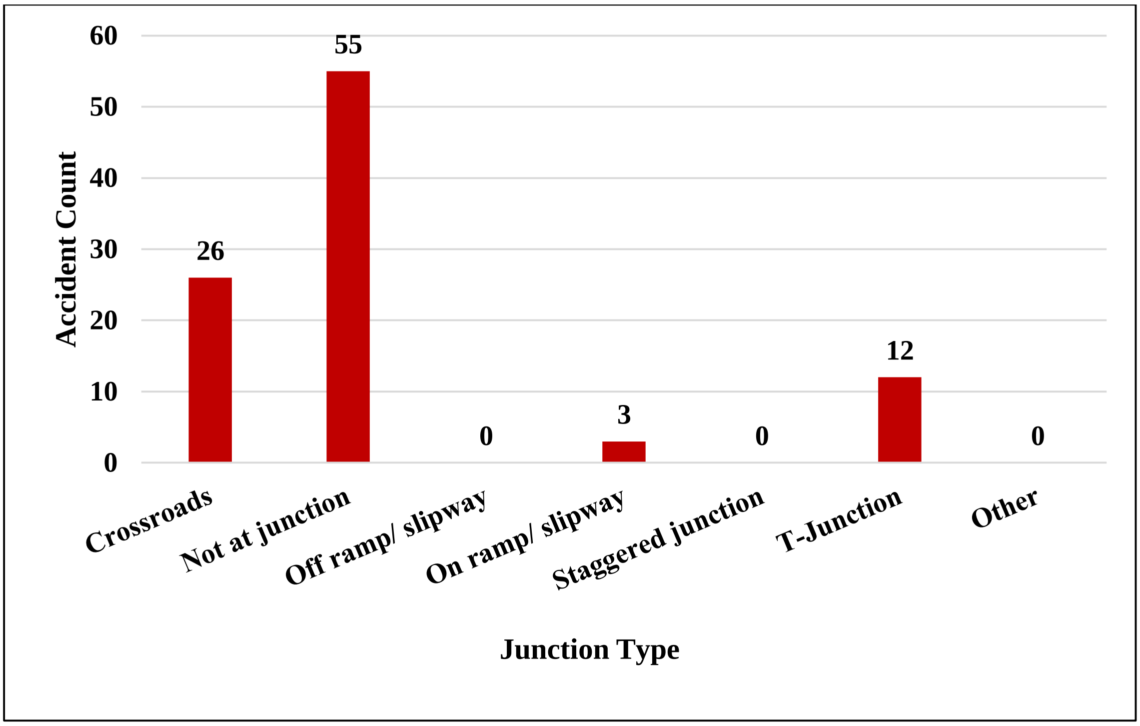
Appendix 4.8b Fatal Accidents by Junction Type in 2012



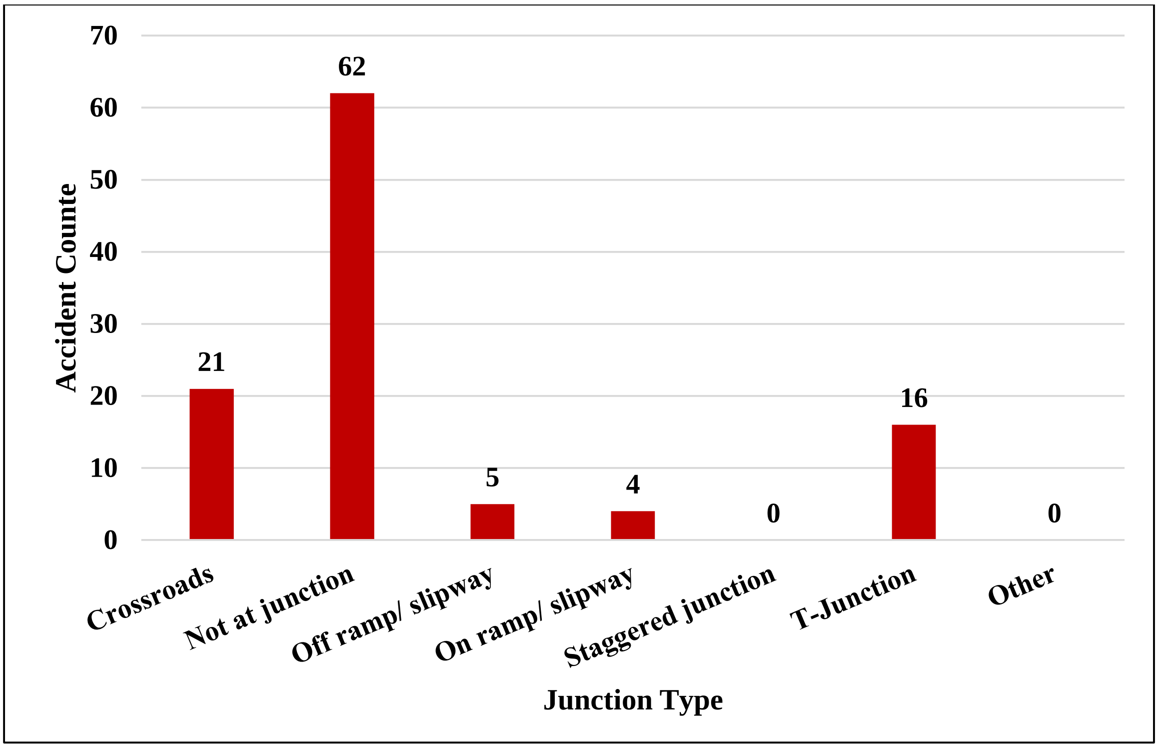
Appendix 4.8c Fatal Accidents by Junction Type in 2013



Appendix 4.8d Fatal Accidents by Junction Type in 2014

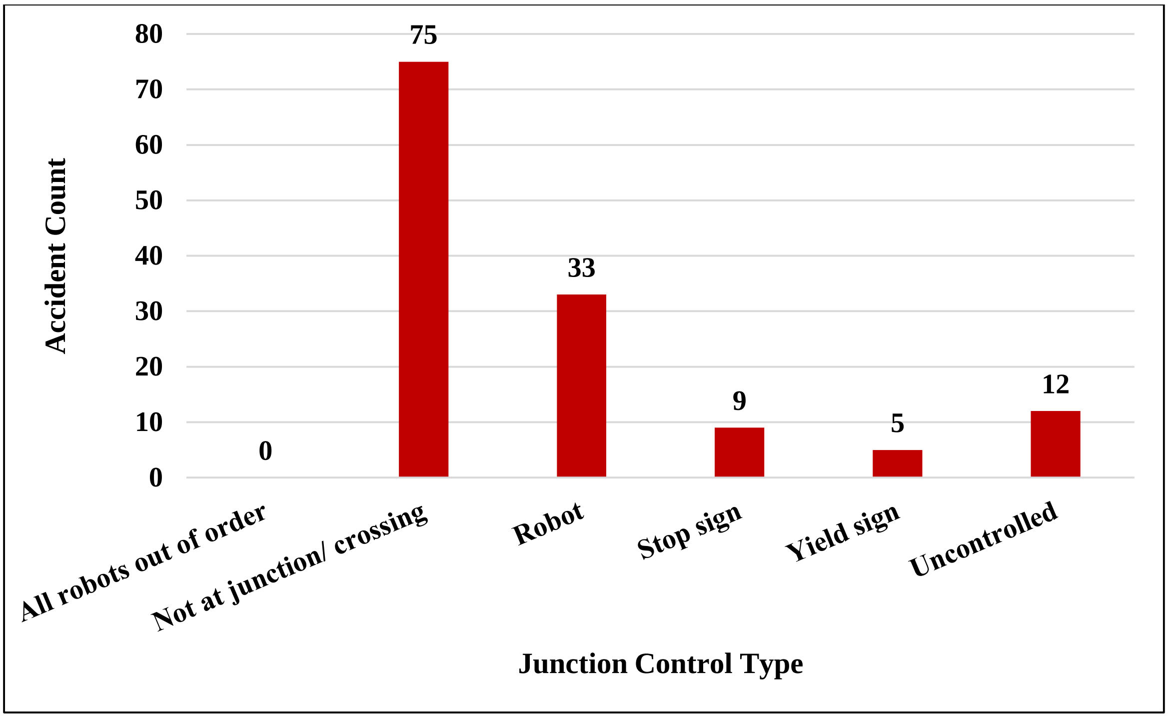


Appendix 4.8e Fatal Accidents by Junction Type in 2015

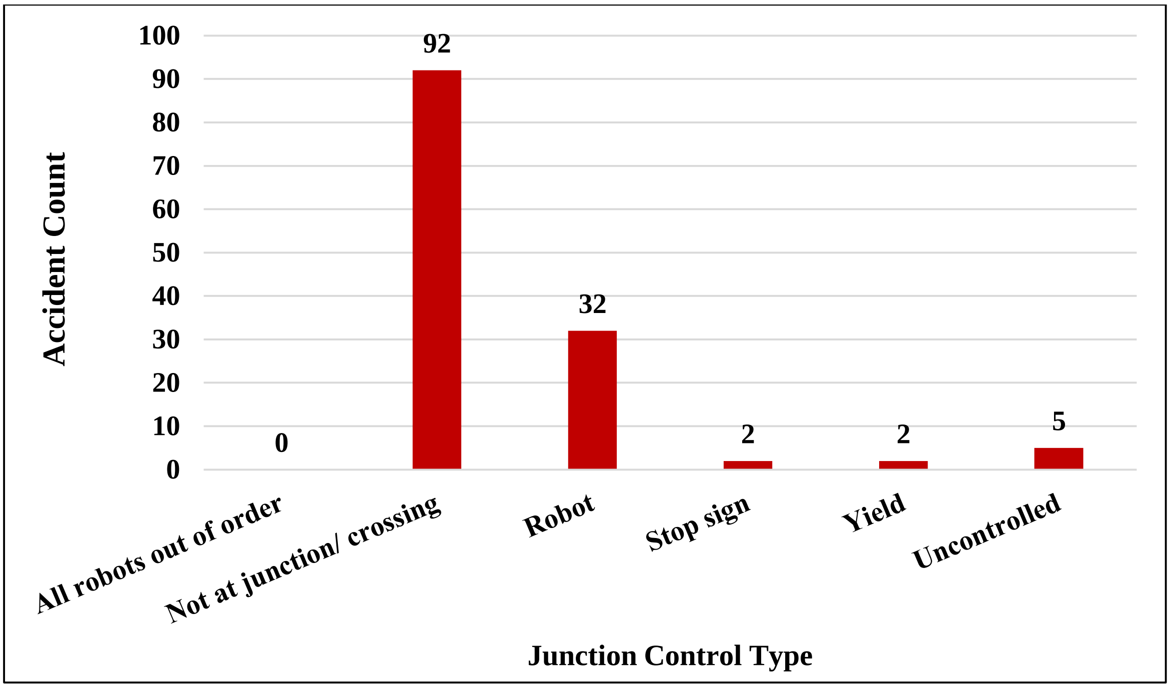


Appendix 4.9 Fatal Accidents by Junction Control Type

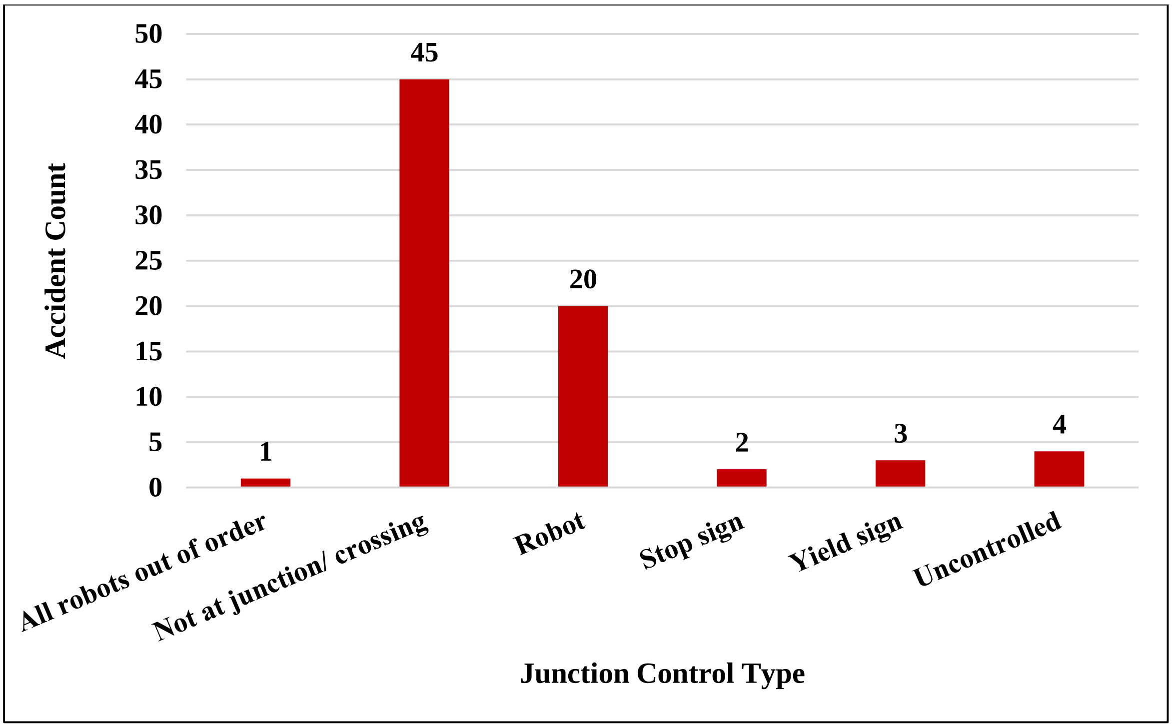
Appendix 4.9a Fatal Accidents by Junction Control Type in 2011



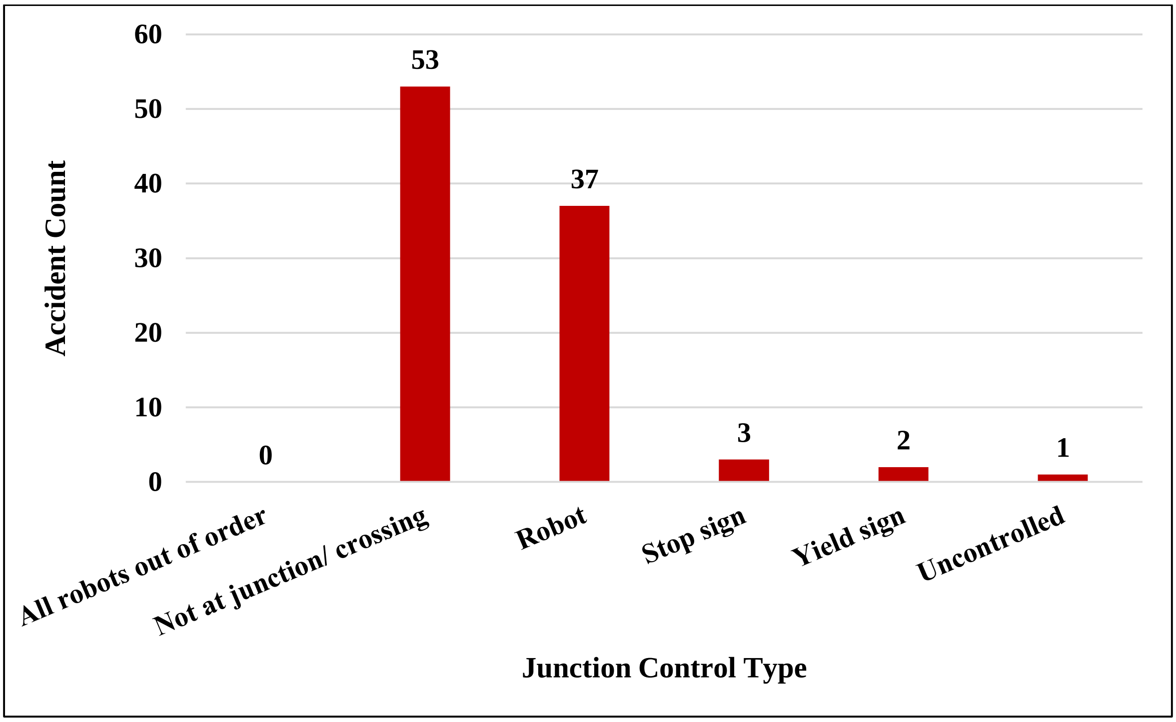
Appendix 4.9b Fatal Accidents by Junction Control Type in 2012



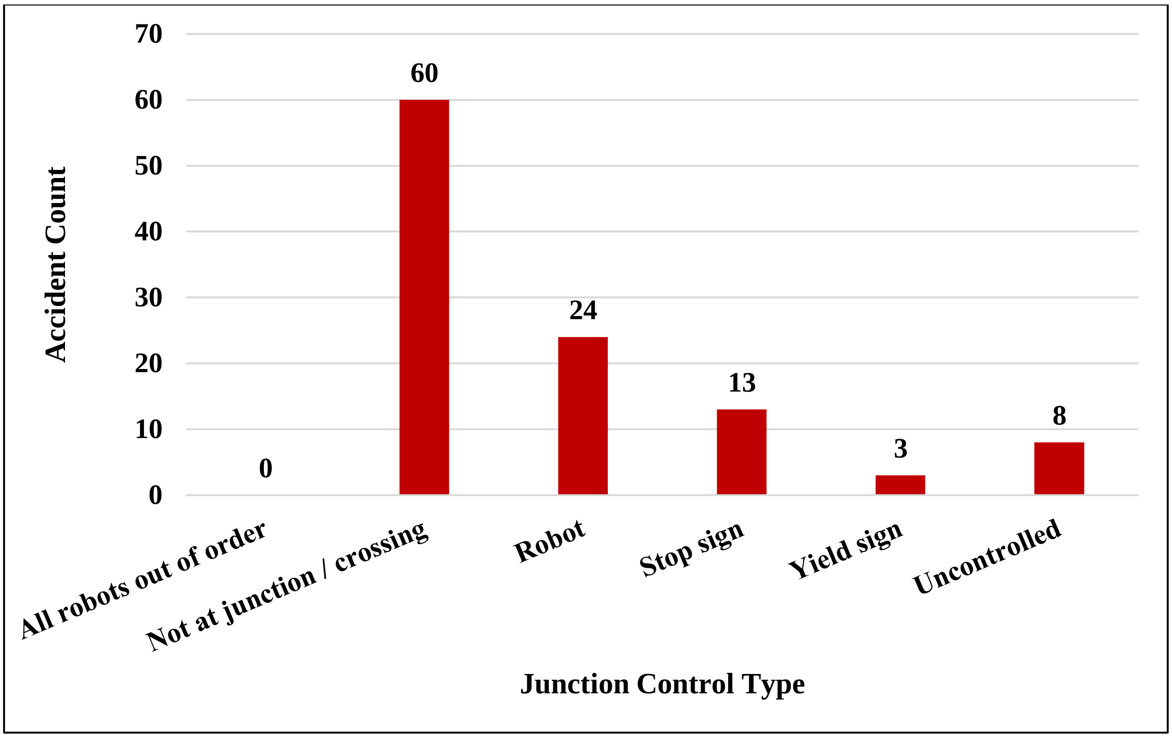
Appendix 4.9c Fatal Accidents by Junction Control Type in 2013



Appendix 4.9d Fatal Accidents by Junction Control Type in 2014

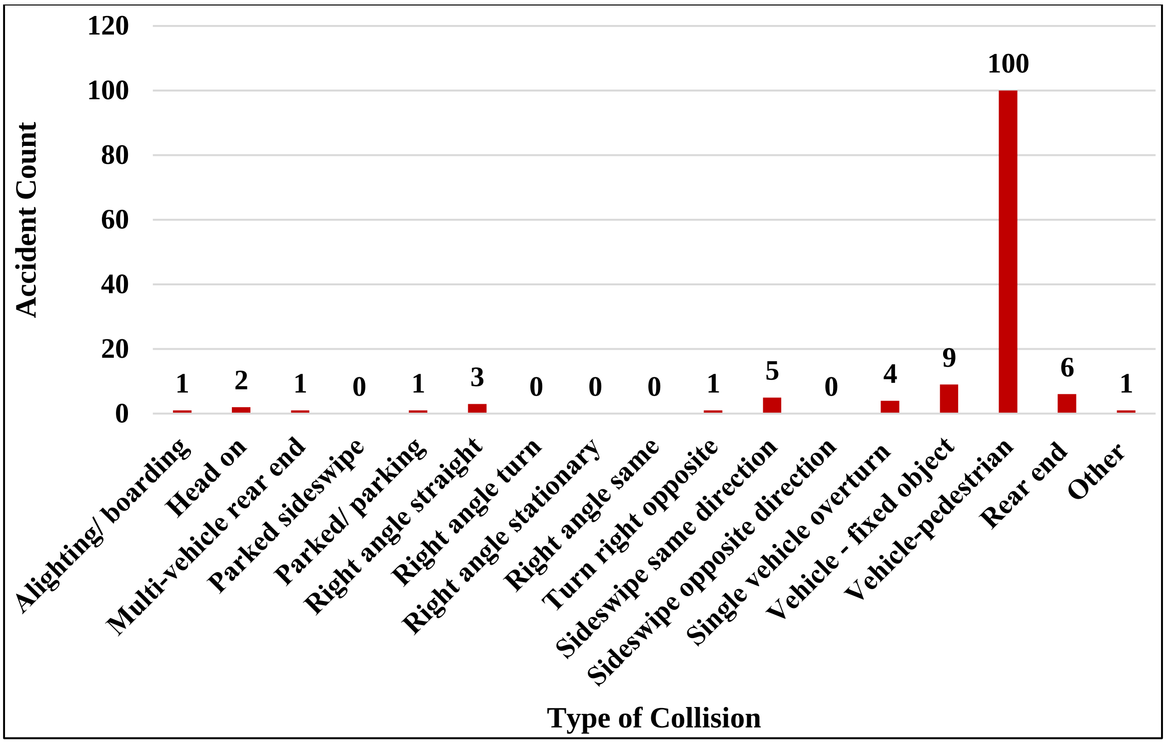


Appendix 4.9e Fatal Accidents by Junction Control Type in 2015

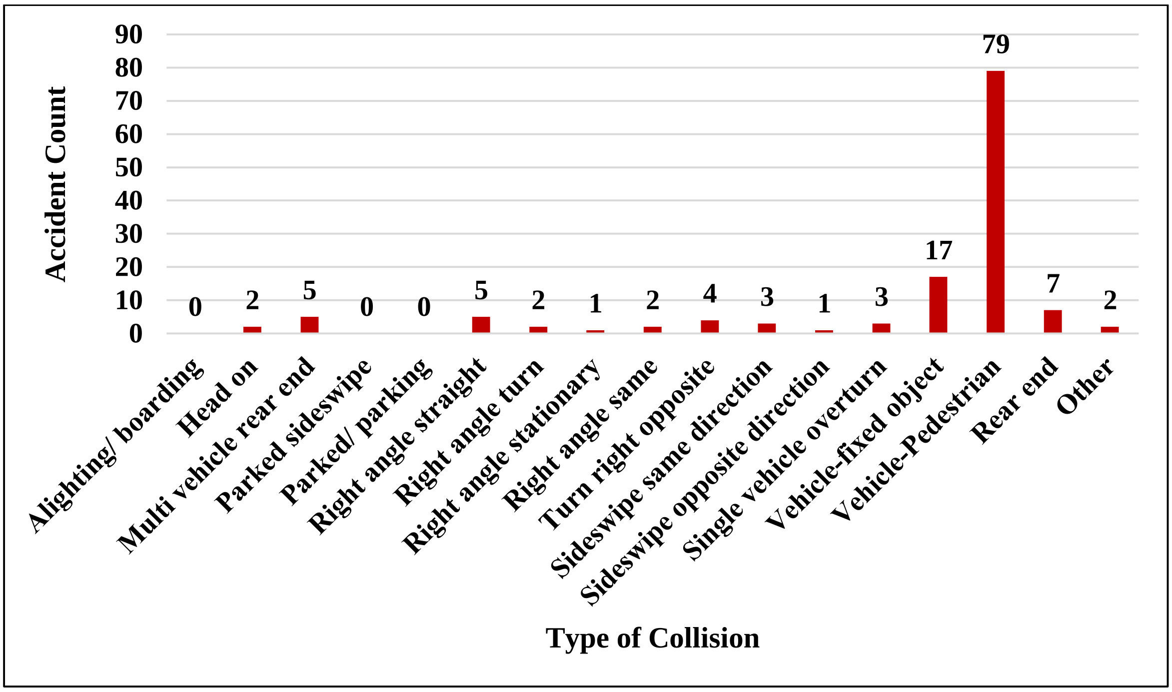


Appendix 4.10 Fatal Accidents by Type of Collision

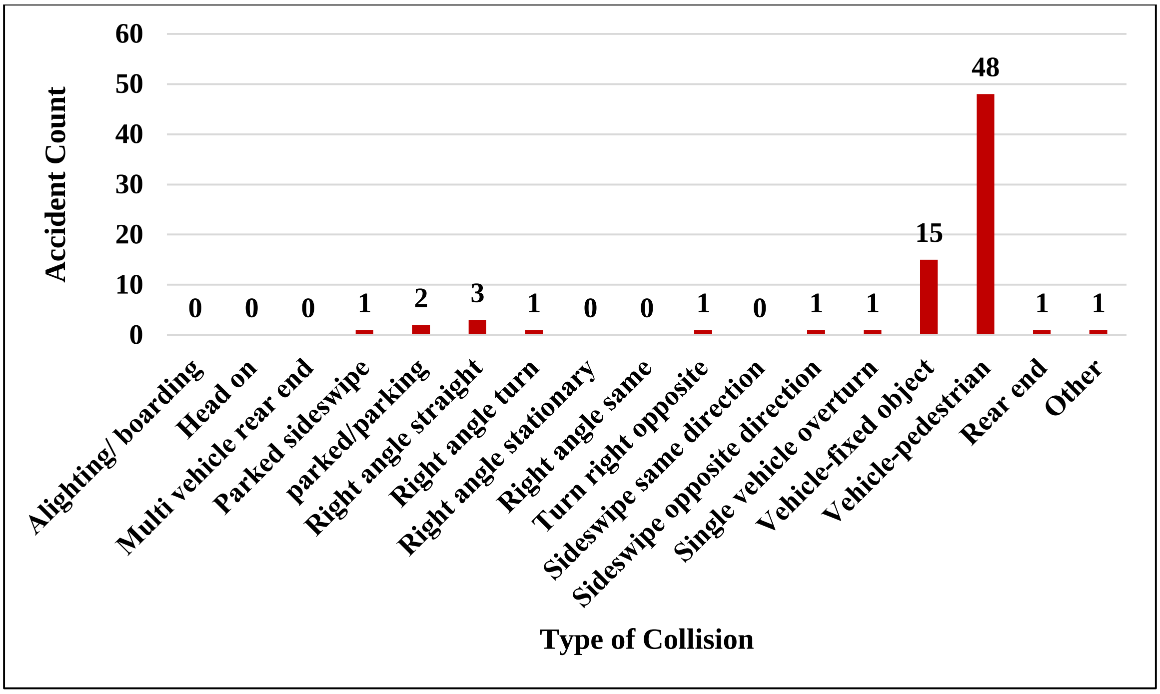
Appendix 4.10a Fatal Accidents by Type of Collision in 2011



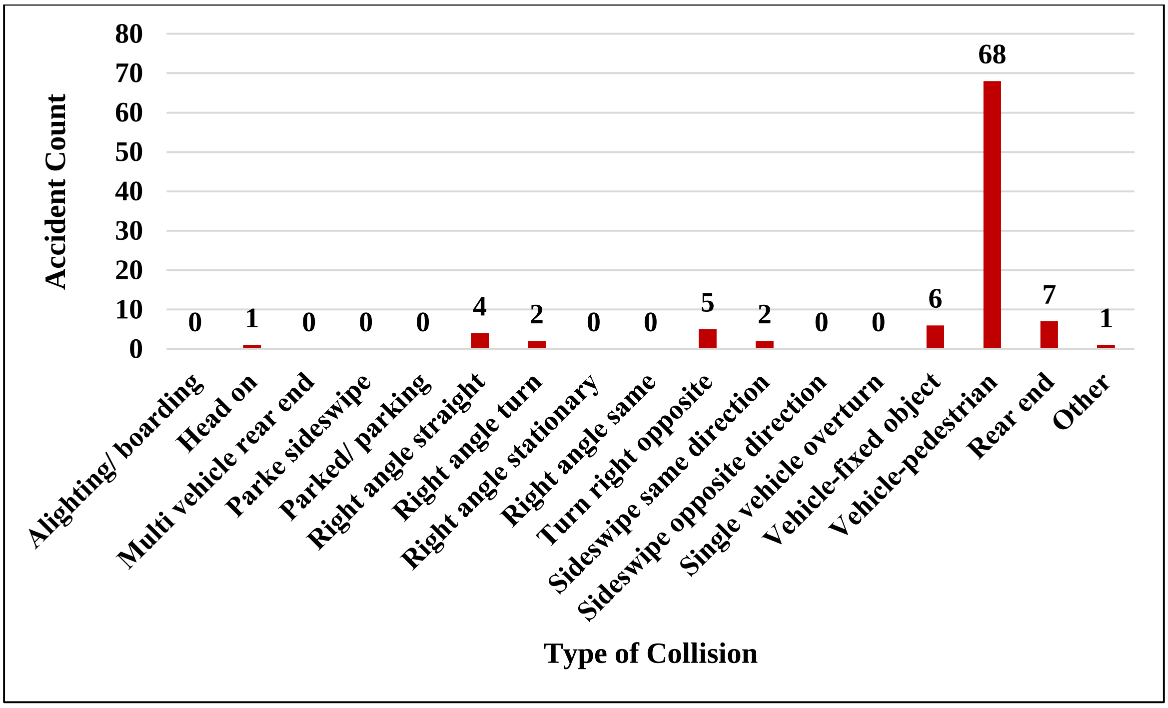
Appendix 4.10b Fatal Accidents by Type of Collision in 2012



Appendix 4.10c Fatal Accidents by Type of Collision in 2013



Appendix 4.10d Fatal Accidents by Type of Collision in 2014



Appendix 4.10e Fatal Accidents by Type of Collision in 2015