Original Contributions

Urban density, deprivation and road safety: A small area study in the eThekwini metropolitan area, South Africa

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ABSTRACT

Following a general paucity of small area research on road traffic injuries (RTIs), this study examined small area variations in RTIs for the eThekwini Metropolitan Area (comprising predominantly the City of Durban) in South Africa. Population density was used as an organising framework to examine variations in RTI outcomes, and correspondence with a range of measures relating to characteristics of the crashes and to socio-economic deprivation. Analyses were undertaken at the suburb level, using data from 2005–2009 and employing a cross-sectional geographical design. Analyses were also undertaken for disaggregated injury, crash severity, and road user groups. The distribution of the injury outcome measures corresponded with several measures that proxied risks relating to excessive driving speeds, excessive travel exposure, and general social as well as area level deprivation. Negative binomial models, fitted for the injury outcome measures, showed population density to be a significant predictor of all injury outcomes but also that its effects was only partially explained by the explanatory measures considered. The findings on deprivation provide new insights to rural-urban variations in RTIs, at least in the South African setting. The findings also have implications for informing integrated developmental policies and strategies across a range of disciplines and departments, especially at the city level.

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INTRODUCTION

The occurrence of road traffic crashes and injuries are particularly sensitive to the effects of population density (Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri, Egger & von Elm, 2011). This may be especially apparent for cities and other urban centres subject to disparate and changing levels of population density through urbanisation and other related processes of suburbanisation, urban sprawl and fragmented forms of development. Whilst cities tend to hold promise of prosperity, with rapid rates of urbanisation, municipalities struggle to cope with the provision of essential services and infrastructure such that opportunities are unevenly distributed and are often accompanied by a multitude of deprivations that pose major challenges to the health and safety of vulnerable populations. Given that the majority of the world's population are now living in cities and other urban centres, and that urban populations in developing countries are forecast to double between 2000 and 2030 (World Health Organization, WHO & United Nations HABITAT, UN-HABITAT, 2010), the health and safety of urban populations is a major concern.

Levels of urbanity or rurality have been shown to be an important discriminator of the geographical distribution of risk exposure and the occurrence of RTIs, along with contributory influences of the social and physical environments. For instance, evidence focussed on various geographical areas has shown a consistent inverse association between death from road traffic crashes and population density, which is commonly used to proxy the effects of rurality or urbanity in coarse-scaled geographical analyses (Noland & Quddus, 2004; Scheiner & Holz-Rau, 2011; Spoerri et al., 2011). Noland and Quddus (2004) in a study of 8,414 wards in England, showed urbanised areas with higher densities had fewer casualties, especially fatalities, but also areas of higher employment density tended to have more casualties. The authors used negative binomial count models to control for a range of area level factors including land use types such as population density, road characteristics such as the number of roundabouts and junctions, demographic characteristics such as deprivation, and proxies for traffic flow such as measures of employment. Spoerri et al. (2011) in a geographical study of road traffic fatalities (RTFs) at the municipality level in Switzerland, found road traffic mortality to increase with decreasing population density, but only for the motor vehicle occupant road user group. Inverse relationships between population density and death from RTIs has been shown for the South African setting in a coarse-scaled geographical analysis of RTFs that examined a large range of social and environmental influences (Sukhai & Jones, 2013). In this study, population density was the strongest predictor of the geographical variations in RTFs. The reasons for these effects have however not been investigated for the South African context.

The potential causal mechanisms that link population density to road traffic accident risk are numerous. The high burden of road traffic deaths in low density rural areas, and predominantly in high income countries, is often attributed to poorer injury outcomes due to inadequate access to quality pre-hospital and advanced in-hospital trauma care (Baker, Whitfield & O'Neill, 1987; Van Beeck, Mackenbach, Looman & Kunst, 1991) and relatively higher levels of risky driving behaviours such as drinking and driving, excessive driving speeds and non-wearing of seatbelts (Besag & Newell, 1991; Dumbaugh & Rae, 2009; Strine, Beck, Bolen, Okoro, Dhingra & Balluz, 2010). Van Beeck et al. (1991) showed that in the Netherlands, advanced trauma care along with traffic density were key predictors of regional variations in traffic mortality, showing an inverse relationship with case fatalities. Strine et al. (2010) examined self-reported seat belt use across the United States by adjusting for seat belt law and several other factors such as socio-demographic characteristics. They found respondents in the most densely populated metropolitan areas were significantly more likely to report wearing seatbelts compared to their most rural counterparts (adjusted odds ratio = 2.9).

We suggest that the effects of population density on health and safety, and in particular its influences on different road traffic outcomes, may be more apparent for small areas within cities and other urban centres, and these thus provide a useful context for understanding geographical influences on road safety. Small areas generally comprise geographical classifications below the level of health or local authority district. They often display greater social homogeneity as compared to census-level administrative units, and thus are regarded as more suitable units of analysis in epidemiology (Carstairs, 1981; Haining, Wise & Blake, 1994; Haynes, Lovett, Reading, Langford & Gale, 1999). For example, Haynes et al. (1999) compared a range of social and demographic predictors of crash rates in pre-school children using census enumeration districts, wards and specially constructed social areas, and found specially constructed small areas to yield the best fitting models.

Consistent with a paucity of small area studies on RTFs internationally, to the best of our knowledge, small area studies of RTIs have not been conducted in South Africa. Such studies are important for the South African traffic context. Geographical variations in health and safety conditions are largely related to socio-spatial patterns arising from historical urban planning policies under the apartheid regime that dictated where people could and could not live (see Coovadia, Jewkes, Barron, Sanders & McIntyre, 2009; Seedat, Van Niekerk, Jewkes, Suffla, & Ratele, 2009). Further, large-scale migration of deprived populations to urban and urban fringe areas has allowed for an "urbanisation of poverty" (Ravallion, Chen & Sangraula, 2007), commonly associated with informal settlements and other housing deprivation. Finally, South African cities typically show large variability in population densities arising from the combined processes of urbanisation with pockets of informal settlements close to the city, urban sprawl, and historical forced removals with high population density township developments in the outskirts of the city. The effects of such disparate population densities on the health and safety of affected populations are however generally unknown.

This study seeks to contribute to our understanding of the geography of RTIs in South Africa by examining small area variations in RTIs and its influences for the eThekwini Metropolitan Area (EMA, incorporating the city of Durban). The EMA is particularly illustrative of the socio-political history of the country, characterised by high levels of socio-economic and spatial disparities and injuries (eThekwini Municipality, 2011; South African Medical Research Council-University of South Africa Crime Violence and Injury Lead Programme, SAMRC-UNISA CVILP, 2005), providing a relevant test bed to explore small area variations in RTIs. Following the significant influences of population density on road traffic crashes and injuries, found especially in coarse scaled studies, population density is used as an organising framework in this research to explore the influences on RTIs, and help elucidate some of the possible drivers to these relationships at a small area level. In particular, the role of social and area deprivation as well as the characteristics of crashes in explaining the injury outcomes by population density is examined.

METHODS

The study was based on a cross-sectional geographical design at the suburb level for the EMA. Suburbs, contained within cities and other urban centres, are not part of the census geographical hierarchy but rather represent city planning and service delivery units. In displaying greater social homogeneity as compared to census areas, suburbs may thus be regarded as relatively more appropriate entities for research on injury prevention and safety promotion. In order to reduce the effects of random year-to-year variation, aggregated data for the five-year period from 2005-2009 were used.

STUDY SETTING

The study setting is the EMA, which is one of eight metropolitan areas in South Africa and is located in the province of KwaZulu Natal (KZN). The EMA is the largest city within KZN and has a land area of approximately 2,300 km^2 and a population of approximately 3.5 million people (eThekwini Municipality, 2011). The EMA shows a fragmented urban form that reflects the diverse physical topography of the metropolitan area as well as remnants of distorted urban planning arising from historical apartheid-related policies and practices. The resultant highly uneven distribution of the population manifests in large clusters of residential development together with relatively low density urban sprawl as well as a peripheral location with much of its deprived populations (Breetzke, 2009). In addition, high levels of associated crime and violence have also resulted in large scale decentralisation of retail and commercial activities as well as the upmarket development of numerous gated communities.

In addition, the EMA also contains large tracts of rural areas. Based on census classification, only 35% of the land area is considered as predominantly urban, with more than 80% of the population living in these areas (eThekwini Municipality, 2011). The Statistics South Africa census definition of urban and rural areas is based on the dominant settlement type and land use within Enumerator Areas (EAs), which is the lowest geographical level used for non-population based census dissemination (Statistics South Africa, StatsSA, 2003; StatsSA, 2004). Typical urban settlements are cities, towns, townships, and suburbs whilst rural areas typically tend to contain tribal areas, commercial farms and rural informal settlements (StatsSA, 2004).

The EMA is also characterised by large economic diversity. With an annual average economic growth of 3.7% from 2004-2009, compared to 3.4% for the province and 3.3% for the country (eThekwini Municipality, 2011), the economy of the EMA may be regarded as relatively progressive. However, the EMA is also characterised by increasing levels of poverty and inequality as well as by having the highest rate of unemployment of all metropolitan areas in the country. In 2004, estimates indicated that 31% of the population were living in poverty, 34% were unemployed, and the Gini coefficient, a measure of inequality ranging from 0 (perfect equality) to 1 (perfect inequality), was at 0.60 (Dray, McGill, Muller, Muller & Skinner, 2006). The Inanda/ Ntuzuma/ KwaMashu complex (INK) in the Metro is also one of 7 urban and 22 total presidential poverty nodes that represent the largest concentrations of poverty in SA and that are earmarked for accelerated development (Department of Provincial and Local Government, DPLG & Business Trust, 2007).

DATA FOR ROAD TRAFFIC INJURY AND EXPLANATORY VARIABLES

Table 1 details the measures relating to injury outcomes, crash characteristics, and socio-economic deprivation considered for this study. Aggregated suburb-level data on RTIs and crashes were provided by the eThekwini Transport Authority (ETA) for 2005-2009. Data from the ETA were based on accident report forms completed by police personnel, plus reports made to the police by members of the public involved in road traffic crashes. In terms of fatal injuries, cases with death occurring up to six days after a collision are considered by the ETA. Injuries requiring hospitalisation were considered to be serious injuries. Population-based fatal and serious injury rates were considered for analysis. Following the particular area-level risks for pedestrian injuries such as inadequate infrastructure for crossing or separation from motorised traffic, analyses are also undertaken separately for the pedestrian road user group. Population density for our study was based on population counts from the 2001 census, which was the latest census data available.

Table 1: Summary of explanatory measures

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

Table 2 summarises the hypothesised associations and relevant literature pertaining to the explanatory measures considered for analysis. A range of indicators covering the domains of time variant risks, weather, driver behaviour, crash and vehicle types, population socio-demographic status, and road user types were considered.

Table 2: Summary of literature on selected explanatory measures

Explanatory effects	Associations	References
Temporal patterns		
Evenings hours and weekends	Higher fatal injuries	Sukhai et al., 2009; Peden et al., 2004
Weather		
Rainfall	Higher risk of injury crashes in rainy conditions	Brodsky & Hakkert, 1988
High risk driving behaviours		
DUI, speeding, non-wearing of seatbelts	Higher injury rates in low density rural areas	Strine et al., 2010; Dumbaugh & Rae, 2009; Besag & Newell, 1991
Crash and vehicle types		
Speed-related single vehicle crashes among young drivers	Higher crashes	Chen et al., 2009
Pedestrian injuries involving sport utility vehicles and pick-up trucks	Higher injury severity scores	Ballesteros, Dischinger & Langenberg, 2004
Involvement of large trucks in rural crashes	Higher crash risk	Muelleman & Mueller, 1996; Lyles, Campbell, Blower & Stamatiadis, 1991
Socio-economic status and deprivation		
Socio-economic status	Higher crashes and RTIs with lower socio-economic status	Sukhai and Jones, 2013; Spoerri et al., 2011; Rivas-Ruiz, Perea-Milla & Jimenez-Puente, 2007; Borrell et al., 2005; Christie, 1995
Deprived communities	Higher traffic-related risk exposure in deprived communities	Babio & Daponte-Codina, 2006; Sonkin, Edwards, Roberts & Green, 2006; Macpherson, Roberts & Pless, 1998
Population and road user groups		
Vehicle occupants	Higher fatal injuries in rural areas in low density rural areas	Spoerri et al., 2011; Muelleman & Mueller, 1996; Chen, Maio, Green & Burney, 1995
Pedestrians	Higher risk and injury in urban areas	Scheiner & Holz-Rau, 2011; Petch & Henson, 2000
Child pedestrians	Higher risk of injury in urban areas	Scheiner & Holz-Rau, 2011; Petch & Henson, 2000

ASSIGNING ROAD TRAFFIC INJURY AND EXPLANATORY DATA TO SUBURBS

Boundary data for the suburbs were obtained for planning units that are utilised by the municipality for management and service delivery. The planning unit areas matched that of the suburbs closely, and they comprised census Sub-places and Main Places or combinations of them. Sub-places and Main Places represent the second and third lowest census levels, after EAs (StatsSA, 2004). Sub-places generally include suburbs, sections of a township, smallholdings, villages, sub-villages, wards or informal settlements, while Main Places generally include cities, towns, townships, tribal authorities and administrative areas (StatsSA, 2004). Hence, areas from the non-census suburb classification may straddle both Main place and Sub-place census levels, especially in the case of towns, townships and informal settlements. The municipal boundary data were then adapted (mostly through renaming and merging some areas) and integrated with the suburb-level traffic data from the ETA within a Geographical Information System (GIS) (ArcGIS 9.3). Five of the suburb areas, which were demarcated to an expanded area of the EMA in 2001 (eThekwini Municipality, 2002), did not have data available. A total of 68 remaining suburbs were considered for analyses. The suburbs differed markedly by size; the mean area was 30.0 km^2, ranging from 2.2 km^2 for Canelands in the North to 160.6 km^2 for the Adams/ Folweni/ Sobonakhona cluster in the South.

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

CALCULATION AND EXPRESSION OF OUTCOME AND EXPLANATORY MEASURES

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

Following the lack of a clear linear relationship between population density and RTIs, evidenced at the coarse-scaled DC census level across the country using several exposure-based indicators (Sukhai, Jones & Haynes, 2009), relationships with population density in this study were explored using quartiles. Population-based rates for the injury outcomes and population percentages for the explanatory measures were calculated separately for each of the population density quartiles.

STATISTICAL ANALYSIS

Using the IBM SPSS Statistics version 19 software, univariate analyses was used to summarise the distribution of the outcome and risk-related variables listed in Table 1. The Pearson's correlation coefficient and associated P-value were calculated to test the strength in the relationship between variables.

The software was also used to undertake linear regression analyses to test for linear trend across quartiles for the different measures, and to model the predictors of the road traffic outcomes for the EMA. To identify the presence of linear trend across the population density quartiles, the slope lines for the rates and proportions for the injury outcomes and explanatory measures were examined, and tested if the fitted lines were significantly different from zero. For the predictive modelling, negative binomial regression models were fitted for the 4 outcome measures, using the natural logarithmic transformation of the population size variable as an offset. The negative binomial count model was used to accommodate overdispersion in the dependant variable. Only variables showing a statistically significant association with the respective outcome measures were included in the models. For similar measures within the day, time and social deprivation groups, only that which contributed best to model fit was selected from each group. The regression models were fitted using a backward elimination process whereby non-significant variables were removed sequentially starting with the least statistically significant and continuing until only the statistically significant predictors remained.

RESULTS

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

Table 1 shows the leading day for crashes to be Saturdays, accounting for nearly one-fifth of all crashes. Nearly one-quarter occurred at night and nearly one-fifth during the evening peak hour period from 4-6pm. About one-tenth occurred when the road surface was wet. Crashes occurring whilst turning and with a fixed roadside object were the most common type, accounting for about 10% each of all events. More than half the vehicles involved in the crashes were cars, followed by roughly one-fifth light delivery vehicles. In terms of the socio-economic deprivation, on average for the suburbs, little under one-fifth of the population have less than a secondary level of education, and the same proportion are unemployed. Of those that are employed, about two-thirds of them earn a monthly income of R400 or less.

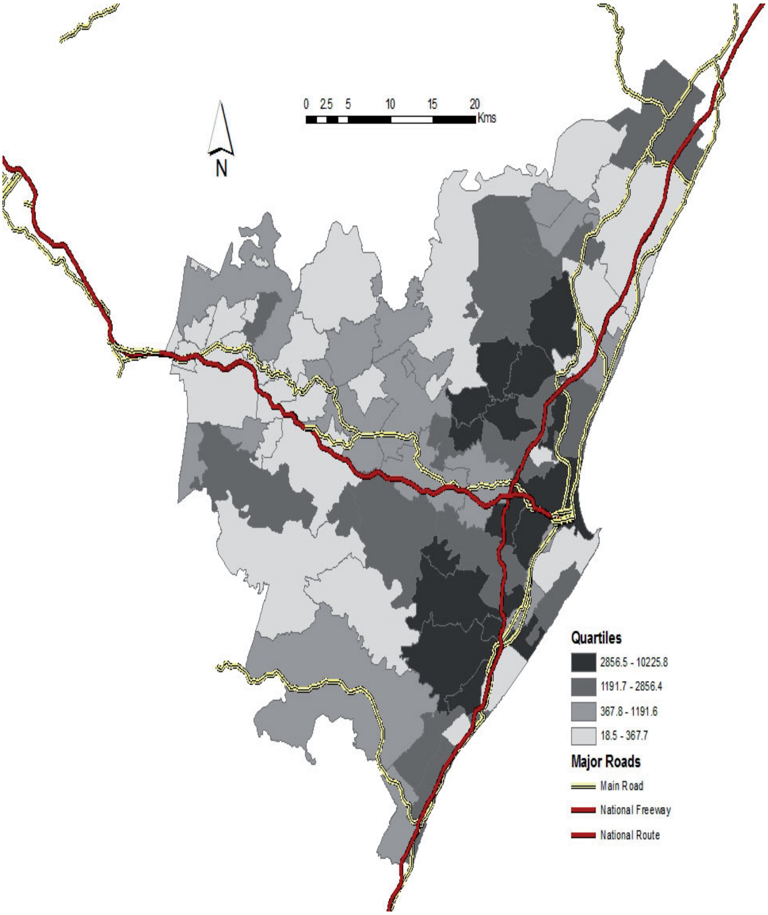

Figure 1: Population density of EMA suburbs

The average population density across the suburbs was 2,053.7 persons per square kilometre (S.D. 2 284.2), ranging from 18.5 to 10,225.8. Figure 1 shows the geographical distribution of the population density measure. The distribution shows three clusters of suburbs with very high population densities: the city centre and surrounding suburbs (central East coast of city); the northern township areas, including much of the INK complex and Phoenix; and township areas in the south, including Umlazi and Chatsworth.

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

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

In terms of socio-economic deprivation, the relatively higher injury rates in low density areas, specifically in quartile 1, are shown to be accompanied by higher percentages of the population that have less than a secondary level of education, and by the percentage of income earners that receive a monthly income of R400 or less.

In order to explicate some of the effects arising from population density, and based on the data available, Table 4 compares the coefficients for population density from an unadjusted and an adjusted model that adjusts for other statistically significant coefficients, for the four count-related outcome measures considered for this study. The adjustment covariates were the percentage of crashes involving fixed objects (for all injury outcomes); percentage articulated vehicles (for all injury outcomes except pedestrian serious injury); percentage

Table 3: Injury outcome by quartiles of crude population density

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

* 5-year rate (2005–2009)

of minibus taxis (for overall and pedestrian fatal injuries); percentage of crashes occurring during afternoon peak hours, and percentage unemployed population (both for overall serious injuries); and lastly the income deprivation measure of percentage population earning less than R400 (for serious pedestrian injury). Of note is that although the effect of population density is attenuated in the adjusted models due to the effects of other explanatory variables that explain the outcomes, it remains still statistically significant along with these effects.

Table 4: Population density effect from unadjusted and adjusted models for injury outcomes

	Unadjusted model				Adjusted model			
	Coefficient	Standardised coefficient	S.E	P-value	Coefficient	Standardised coefficient	S.E	P-value
Fatal injury	-3.19	-129.31	0.44	<0.001	-2.04	-82.70	0.55	<0.001
Fatal pedestrian injury	-2.46	-134.84	0.46	<0.001	-1.34	-73.45	0.56	0.017
Serious injury	-2.59	-12.80	0.45	<0.001	-1.83	-9.05	0.59	0.002
Serious pedestrian injury	-1.51	-10.02	0.47	0.001	-1.38	-9.16	0.50	0.006

DISCUSSION

POPULATION DENSITY AND RTIs

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

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

CRASH CHARACTERISTICS AND RTIs

In terms of population-based rates, many of the characteristics of the crashes showing higher percentages in the relatively lower population density suburbs (quartiles 1-3), such as those involving single vehicles that overturned, animals and fixed objects, and occurring on wet roads, may be suggestive of the involvement of excessive driving speeds as evidenced elsewhere (Brodsky & Hakkert, 1988; Chen et al., 2009; Peden et al., 2004). Excessive speed is also commonly cited as one of the reasons for relatively higher injury rates in low density rural settings, along with other high risk behaviours such as drinking and driving and non-wearing of seatbelts (Besag & Newell, 1991; Dumbaugh & Rae, 2009; Strine et al., 2010). The measure for the percentage of crashes involving articulated vehicles also showed a positive association with the population-based rates. Whilst the relatively higher involvement of large trucks in rural crashes has previously been described in settings such as the United States (Lyles, Campbell, Blower & Stamatiadis, 1991; Muelleman & Mueller, 1996), the data on crash characteristics in our study are restricted to prevalence rather than crash risk.

In terms of the crash severity measure, as expected, higher crash severity was shown to be associated with a relatively higher involvement of high passenger occupancy vehicles such as buses, minibuses and LDVs. Higher crash severities were also accompanied by higher percentages of cases occurring over weekends and at night. These may relate to high risk driving behaviours, the weekend cases involving high occupancy public transport vehicles may also relate to higher levels of mobility and travel exposure due to relatively higher recreational travel, and the need to travel longer distances to services, or homesteads in the case of migrant workers.

SOCIO-ECONOMIC DEPRIVATION AND RTIS

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

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

IMPLICATIONS FOR PREVENTION

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

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

The policy and practice implications from this study may also align with current city-related initiatives that were detailed by the Minister of Finance in his 2012 annual budget speech

(Gordhan, 2012). These include a “Cities Support Programme”, focussed on improved spatial planning, public transport systems, and management of infrastructure utilities as well as a “Municipal Infrastructure Support Agency” targeting rural municipalities that lack planning capacity is also proposed. The findings may also be applicable to other metropolitan areas and large cities in the country as socio-spatial disparities and other negative effects from historical policies are not expected to be restricted to the current study setting.

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

STRENGTHS, LIMITATIONS AND FUTURE RESEARCH

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

Our study suffers from three particular limitations. First, typical of small area analyses, our findings are affected by the problem of small sample sizes. Whilst the use of quartile analyses would have helped minimise the small number problem, this potential bias particularly applies to interpretation of findings on the population-based rates. Second, we were restricted to only having data at the group level comprising 68 spatial units, and in the absence of individual level data, we were not able to appraise differences in crash characteristics between the different road user groups. Third, as is often the case with data on crashes and RTIs, under-reporting is a serious challenge. In addition, there may also be an element of geographical bias in the analyses, since under-reporting tends to be a bigger problem in rural than in urban areas (Aptel et al., 1999), and may also be more particular in the case of non-fatal injuries that are less likely to be registered.

Whilst data on pre-hospital and advanced in-hospital trauma care was not available for this study, it would be useful to incorporate such measures in future research, particularly in the South African setting, given the evidence for such effects in other country settings (Baker, et al., 1987; Van Beeck et al., 1991), as well as with our analyses pointing to possible effects that have not been considered. In addition, other GIS-based small area measures such as measures of accessibility or of relative deprivation would be useful, especially towards further understanding the influences of population density on crashes and RTIs. It would also be useful for future predictive-type modelling to build on findings from this research by employing more advanced methodologies including Bayesian approaches to account for small sample sizes (Jia, Muennig & Borawski, 2004; MacNab, 2004).

CONCLUSION

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

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