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Reducing the burden of road traffic injuries and deaths in Ghana: an implementation science approach

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Abstract

Reducing the burden of road traffic injuries and deaths in Ghana: an implementation science approach

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This dissertation comprises four studies that aim to develop contextually relevant evidence on high-risk areas and factors for targeted road traffic injury prevention initiatives in Ghana. We use an implementation science approach by conducting research to understand areas and populations at greater risk that may benefit from evidence-based policies and interventions. The first three studies use a longstanding database maintained by the Building and Road Research Institute of each police-reported motor vehicle collision, minor injury, severe injury, and death. The last study involves in-depth interviews with 24 people in high-risk areas of major roads in Ghana.

In Chapter 1, we provide background on road traffic injuries and deaths, our research objectives, and our approach. In Chapter 2, we identify spatial-specific and precise (i.e., 100-meter locations) clusters of road traffic injury severity on major roads in rural and urban areas

of Ghana using the Getis-Ord Gi* statistic in ArcGIS Pro. We map 35,109 road traffic events from 2017 to 2020 on major roads and weigh outcomes based on severity using a well-known injury severity index. We observed 223 hot spots in rural areas (6.2% of the road network) and 142 injury severity hot spots in urban areas (4.7%) of the road network to target for injury control. We find critical patterns in both types of hot spots, including that urban hot spots are often in the peripheral area of cities where major roads intersect, whereas rural hot spots are sporadic.

In Chapter 3, we analyze spatiotemporal trends in road traffic injury severity, minor injuries, severe injuries, and deaths from 2005 to 2020 using space-time data mining tools (i.e., a space-time cube and emerging hot spot analysis) in ArcGIS Pro. We find the injury severity index and minor injuries significantly decreasing over the period while severe injuries and deaths are on the rise. We identify three specific 2 kilometers (km) by 2 km urban areas and 29 2 km by 2 km rural areas, which are intensifying, defined as hot spots for 90% of the 16 years and with increasing injury severity index scores.

In Chapter 4, we use five years of data (2016 to 2020) to assess and compare factors associated with injury severity among vulnerable road users (VRUs), defined as those without external protection (e.g., pedestrians, powered two-wheeler occupants), to non-vulnerable. We find some factors that consistently increase the odds of severe outcomes, including head-on collisions, at night with no lights or the lights off, and in rural areas or villages. We also explore and compare VRU subgroups (powered two-wheeler occupants, powered three-wheeler occupants, cyclists, and pedestrians) and find substantial heterogeneity in the factors associated with injury severity. Findings indicate that a targeted and road user-specific injury prevention approach is warranted. Targeted interventions for each sub-group could include interventions related to nighttime risks (e.g., lighting, enforcement to reduce excessive speeding) for powered two-wheelers, improved regulation for passengers of powered three-wheelers, and pedestrian-oriented infrastructure.

Lastly, Chapter 5 explores road user perspectives on the magnitude, contributing factors, and potential solutions for road traffic injuries and deaths. We find that participants feel excluded from road safety design, planning, and implementation efforts, despite their complex understanding of the problem's magnitude and contributing factors. An emerging theme was that socio-economic conditions affect increased risks related to road traffic collisions, injuries, and deaths. For example, participants noted that roadside sellers were at higher risk because of their precarious economic status, requiring them to spend substantial time on busy, high-speed roads. Participants describe key implementation issues related to existing interventions, such as a lack of enforcement at certain places or times and poorly designed and built speed calming measures. When prompted for potential solutions, many road users focused on road user behavior and the need for increased enforcement, reflecting a national and global emphasis on changing road user behavior. We call for greater community involvement in road safety to adapt interventions to meet local needs and for the government to acknowledge the gravity of this crisis and allocate resources accordingly.

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DEDICATION

For Mama and Babo, whose sacrifices I could never repay. Thank you for the opportunity to pursue my dreams.

Chapter 1. Introduction

1.1 Background and significance

Motor vehicle collisions (MVCs) result in more than 50 million injuries and 1.35 million deaths globally, 90% of which are in low- and middle-income countries (LMICs) (1, 2). Injuries are the leading cause of death for people aged 5 to 29 and are expected to increase to become the second highest cause of global burden of disease in the next twenty years, due to urbanization, road development, and increasing vehicles and VRUs, defined as those that have limited crash protection, such as pedestrians, cyclists, and motorcyclists (2, 3). Economic losses associated with road traffic injuries and deaths are estimated to be $100 million US Dollars (USD) annually for LMICs (between 2-3% of gross domestic product).

Although there is a substantial burden, research in LMICs is limited; an estimated less than 10% of the total research occurs in limited resource settings despite the overrepresentation of road issues (4). High-income countries (HICs) have made substantial improvements in reducing road traffic injuries and fatalities while progress has stagnated in LMIC, with no reduction in deaths in any low-income country since 2013 (5). Further, findings from HICs may not translate due to the different conditions (e.g., road quality, vehicle safety features), underscoring the importance of studying risk factors and interventions within each context (6). Closely related to risk factors is the importance of understanding which areas and populations are most affected. However, spatial and temporal trends, which are routinely conducted in high-resource settings, are rare in LMICs, largely due to a lack of reliable or high-quality data (7).

There is a need for a comprehensive, contextually relevant understanding of high-risk areas, populations, and risk factors in LMICs to understand which solutions could reduce the burden. Such gaps indicate a need for implementation science. Implementation science can be defined as "the study of methods to promote systematic uptake of research findings and other evidence-based practices into routine practice to improve the quality and effectiveness of health services" (8, 9, 10). The field was developed to address the lack of widespread use of evidence-based interventions (11) and the long period between research and implementation (termed 'the know-do' gap) (12, 13). The field also aims to address inequities (14). A key guiding question for implementation science is "how do we get what works to people who need it with greater speed, fidelity, efficiency, quality, sustainability, and relevant coverage?" (15). We apply this guiding question to our research by aiming to implement what works (evidence-based road safety interventions) to people (vulnerable road users) who need it most (those in high-risk areas) with greater speed and efficiency (15).

Like other LMICs, the burden of road traffic injuries and deaths is staggering and growing in Ghana (5)**.** Annually, there are an estimated 7,018 deaths (27.5 deaths per 100,000 people) (16). The road traffic fatality rate is nearly three times as high as the average for high income countries (8.3 per 100,000 people) (5). Ghana is one of few LMICs in Africa collecting data on MVCs, injuries, and fatalities using standardized definitions, making it uniquely positioned to lead efforts on data-informed road safety decision-making in LMICs. Since 1991, the BRRI under the leadership of the National Road Safety Authority (NRSA), has collected data which includes detailed information on the location, conditions, and outcomes for each MVC, injury, and death in the country.

With this data, there is potential to identify high-risk areas for MVCs, injuries, and deaths for targeted injury prevention efforts. Given the availability of data, longstanding research and implementation collaborations, and the commitment of the government, we believe that Ghana can serve as an exemplar for other LMICs which seek to address road safety issues. Similar exemplar studies have been conducted for other disease areas, including child stunting (17), under-5 mortality (18), and cancer (19). We would suggest that these analyses should be urgently conducted across LMICs, many of which have an alarmingly high road traffic morbidity and mortality burden. Similar countries could benefit from targeting interventions to the most important areas (hot spots), factors (those associated with injury severity), and population needs (derived from road user perceptions on factors causing crashes and potential solutions).

1.2 Dissertation aims

Our overall objective is to develop a contextually relevant understanding of high-risk areas, risk factors, and potential solutions. We plan to do so by:

Aim 1A: Identify significant clusters of road traffic injuries and deaths on major roads

Aim 1B: Analyze spatiotemporal trends in road traffic injuries and deaths on major roads from 2005 to 2020

Aim 2: Assess and compare factors associated with injury severity among vulnerable (pedestrians, cyclists, and occupants of powered two- and three-wheelers) and non-vulnerable road users nationally from 2016-2020

Aim 3: Explore road users' perspectives on the magnitude of, contributing factors, and potential solutions for road traffic injuries and deaths

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1.4 Acronyms

BRRI: The Building and Road Research Institute

DALY: Disability-adjusted life years

GHA: Ghana Highway Authority

HIC: high-income country

IPA: an interpretive phenomenological analysis

LMIC: low- and middle-income country

MVC: road traffic collision

NRSA: National Road Safety Authority

VRU: vulnerable road user

WHO: World Health Organization

Chapter 2. Geospatial analysis of injury severity on major roads in Ghana (2005-2020): Implications for targeted injury prevention and control initiatives

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2.1 Abstract

Road safety authorities in HICs use geospatial motor vehicle collision data for planning hazard reduction and intervention targeting. However, LMICs rarely conduct such geospatial analyses. Since 1991, Ghana has maintained a database of all collisions and is uniquely positioned to lead data-informed road injury prevention and control initiatives. We identified and mapped geospatial patterns of hotspots of collisions, injuries, severe injuries, and deaths using a well-known injury severity index with geographic information systems statistical methods (Getis-Ord Gi*) for four time periods (2005-2008; 2009-2012; 2013-2016; and 2017-2020). We identified specific areas (4.66% of the urban areas and 6.16% of rural areas) to target for injury control. Other LMICs seeking to reduce the burden of road traffic injuries and deaths should conduct similar analyses.

2.2 Introduction

MVCs are a leading cause of injury globally, resulting in more than 50 million injuries and 1.35 million deaths; 90% of these deaths are in LMICs (20). Road traffic injuries are the leading cause of death for people aged five to 29, and the majority are preventable (1, 5). Injuries will increase to become the second highest contributor to the global disease burden in the next twenty years. Factors contributing to this shift include urbanization, suboptimal road development, and increasing interactions between vehicles and VRUs, defined as those with limited collision protection (e.g., pedestrians, motorcyclists) (2, 3). The substantial preventable injury-related morbidity and mortality, particularly in LMICs, results in calls for targeted injury prevention and control strategies.

Governments and road safety authorities in HICs use police- and hospital-reported collision and injury data to assess geospatial patterns as a first step for planning hazard reduction initiatives (21). HICs significantly reduced injuries and fatalities from MVCs, while progress has stagnated in LMICs. There has been no reduction in road deaths in any low-income country since 2013 (5). One of the key issues limiting the ability of policymakers in LMICs to develop and implement effective interventions is a paucity of data regarding the spatial trends of hotspots where MVCs, injuries, and deaths are particularly common (5, 22). However, such data are rarely collected or used in many LMICs to improve road safety (22). There are few geospatial analyses of MVCs in sub-Saharan Africa. What few studies exist often lack spatial specificity, which limits their utility for targeted interventions, programs, and policies (4). Despite the critical importance of data for country-level decision-making, only an estimated 18% of African countries monitor key road safety indicators (e.g., helmet or seatbelt use) (22).

Ghana has a substantial burden of traffic-related injuries and deaths (estimated at 7,018 deaths in 2016; 27.5 deaths per 100,000 people) (16). This death rate is nearly three times as high as the average for HICs (8.3 per 100,000 people) (5). Since 1991, Ghana has been one of few countries in Africa collecting comprehensive and detailed data on MVCs, injuries, and deaths using United Nations (UN)-recommended standardized definitions (e.g., defining a road safety death as someone who is killed immediately or dies within 30 days of the MVC), which makes it uniquely positioned to lead efforts on data-informed road safety decision-making (23). Under the leadership of the NRSA, the BRRI collects police-reported data on the locations, conditions, and outcomes for each MVC, injury, and death in Ghana. Given this rich dataset and the commitment to reducing road injuries and deaths, Ghana can serve as an exemplar for other countries seeking to improve road safety through systematic data collection, targeted interventions, and comprehensive evaluations.

Therefore, we aimed to demonstrate how LMICs can use geospatial data to develop a contextually relevant understanding of high-risk areas for targeted injury prevention and control using Ghana as an example. As part of this overall objective, this study addressed a key research question: "What are the spatial patterns of injury severity in Ghana for four periods (2005-2008; 2009-2012; 2013-2016; 2017-2020)"? We identified and mapped spatial patterns of hotspots of injury severity using a validated injury severity index (24, 25). We used Geographic information systems (GIS) statistical methods (i.e., Getis-Ord Gi* Optimized Hotspot Analysis) to identify statistically significant clusters (i.e., hotspots) for each of the four time periods stratified by urban and rural areas to establish which specific 100-meter locations along national, inter-regional, and regional roads were of greatest risk. This study contributes to the literature on geographically focused public health planning, a field that has expanded rapidly in recent years due to the emergence and availability of GIS software and spatial data (26, 27, 28). By utilizing systematically collected data and exploring geospatial trends, this analysis provides a case study from Ghana that researchers in other LMICs might consider to target similar road hazard reduction interventions.

2.3 Methods

2.3.1 *Theoretical model*

Our work is motivated by the belief that we can achieve the greatest immediate public health impact by focusing on serious traffic-related injuries and deaths versus addressing MVCs more broadly. We are guided by 1) the strong association between the environment and risks of MVCs, injuries, and deaths and 2) the Safe Systems Approach. First, the leading paradigm in injury prevention, Haddon's Matrix, demonstrates the role of the environment in which injury occurs (29). The matrix assesses contributing factors within three components of the epidemiological triad (host, agent, and environment [social and physical]) during three phases (pre-event, event, and post-event) to guide prevention strategies (18). Our work fits this framework's environment component. Advanced geospatial analytic tools can generate detailed data regarding the place of injury occurrence, including information on which populations are most vulnerable to injury and which areas/populations may benefit most from injury prevention and control efforts (16).

Second, the Safe Systems Approach aims to eliminate serious injuries and fatalities by addressing factors related to road users, vehicles, post-collision care, roads, and speeds (30, 31, 32). Two fundamental principles relevant to this work are 1) deaths and serious injuries are unacceptable within a transportation system, and 2) safety is a proactive process requiring identification and prevention before MVCs occur. We pursue an analysis that weights outcomes based on severity to acknowledge that it may not be possible to prevent all MVCs. Still, preventing injuries, severe injuries, or deaths may be possible if we proactively identify, implement, and evaluate measures to improve road safety.

2.3.2 *Data sources*

We collaborated with the Ghana BRRI and Ghana Highway Authority (GHA) to develop and analyze geospatially linked MVC data. BRRI provided data on police reported MVCs in the country from 2005 to 2020. Ghana Police Service personnel responding to an MVC between 2005 and 2020 collected information within several domains, including the driver, passenger, vehicle, environment, and roadway information. MVCs include collisions between vehicles and incidents involving other road users (e.g., pedestrians or bicyclists struck by a vehicle). We have a detailed list of all the collected variables categorized using Haddon's Matrix in the *Appendix.* We obtained the national road network shapefile from GHA.

Additionally, we accessed complementary road network datasets from public sources, including OpenStreetMap and Humanitarian Data Exchange, to corroborate road locations and distances. Discrepancies were discussed and addressed in meetings with BRRI data collection staff. Finally, we used the European Commission's Joint Research Center’s Global Human Settlement Layer data to assess urbanization (33). This dataset describes the degree of urbanization on a one km^2 grid by combining two raster datasets of built-up surfaces (obtained from satellite imagery) and population density from census data.

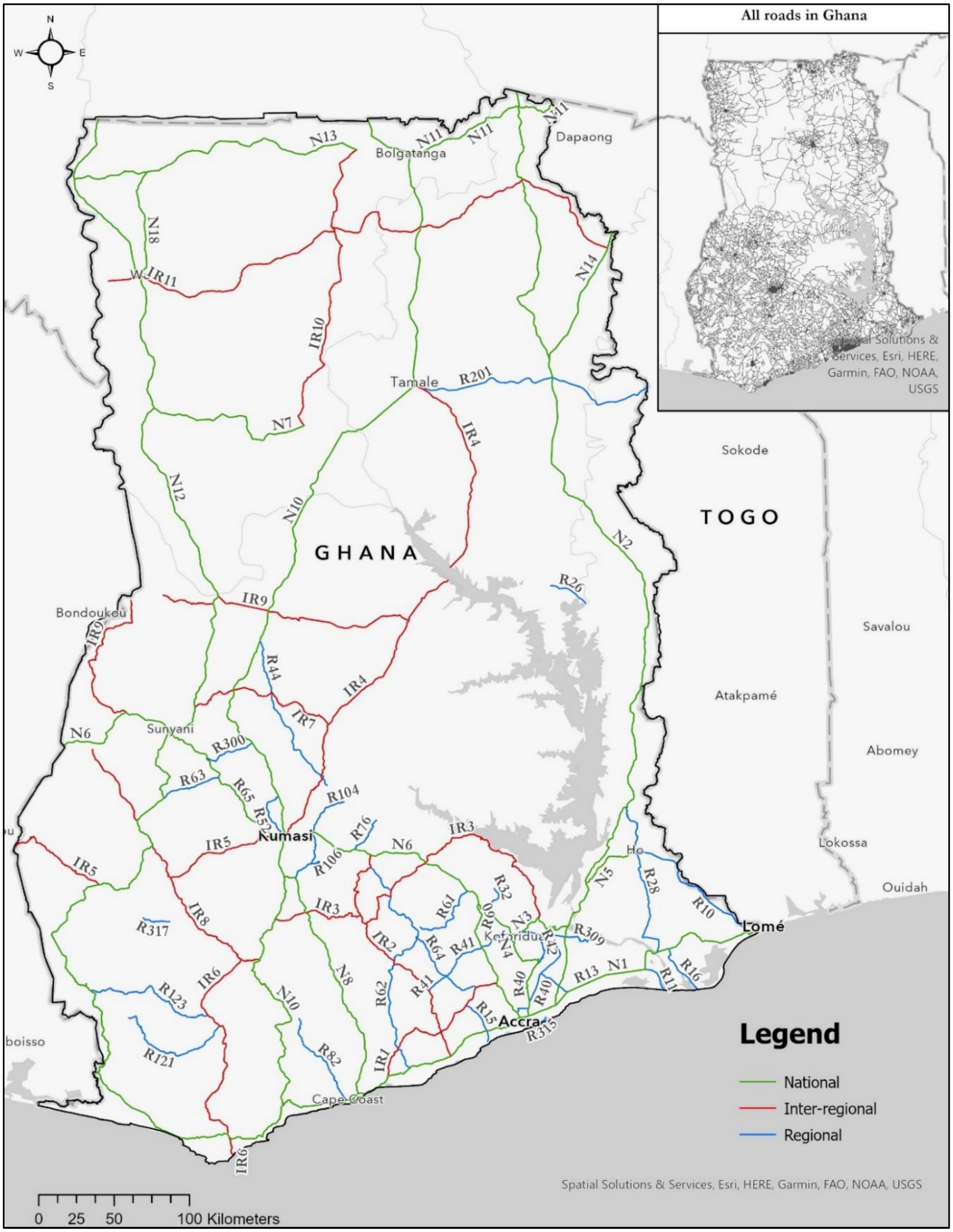
2.3.3 *Ethical approval*

This study received ethical approval from the Committee on Human Research, Publications, and Ethics at the Kwame Nkrumah University of Science and Technology and the University of Washington Human Subjects Division

2.3.4 *Data processing*

The analysis was limited to only MVCs occurring on the trunk road network (i.e., national, inter-regional, and regional highways) as BRRI only collects geospatial data for these MVCs. This report uses the terms trunk and major interchangeably. All geospatial information was gathered and stored as a route number (e.g., National Road 1), direction, km marker (precise 100-meter location along the road), and land marker. To obtain geographic coordinates (i.e., longitude/latitude) for each data point, we established a methodology for geocoding outcomes. First, a road network was developed by triangulating GHA, Open Street Map, Humanitarian Data Exchange, the BRRI's maps/guides, and consulting experts across agencies. Next, we matched this road network with BRRI's data, which included the roadway start and end locations, geo coordinates, meter markers, and landmarks, which allowed the determination of the precise 100-meter location of a collision. Once the road network was mapped and quality-checked, we developed an automated process in ArcGIS Pro for calculating geocoordinates on a projected coordinate system relevant to Ghana (World Geodetic System 1984; Universal Transverse Mercator Zone 30N) (34). Given many roads in the dataset, the observation that many small, regional roads comprise a small percentage of the total collisions, and the manual process of identifying/mapping the roads, we limited the analysis to roads with more than ten MVCs per year. *Figure 2.1* presents all roads included in this analysis and a comparison of those roads compared to all roads in 2022.

Figure 2.1 National, Inter-regional, and regional roads included in the analysis, compared to all roads in Ghana (2022)



2.3.5 *Outcomes*

BRRI reports four outcomes: MVCs resulting in property damage only, MVCs resulting in injury, MVCs resulting in severe injury (defined as requiring hospital care), and MVCs resulting in death. Studies often use MVC, injury, and death counts; however, these do not consider the collision severity. Given our focus on reducing road traffic morbidity and mortality, we employed a well-known indexing system that assigns greater weights to worse collision severity (i.e., property damage < injury < severe injury < death) (*Equation 2.1)* (12, 13). We aggregated all outcomes by time and location to calculate the injury severity index.

Equation 2.1 Injury severity index

$$Injury\ severity\ index = 3 * X_1 + 1.8 * X_2 + 1.3 * X_3 + X_4$$

$$Where:$$

$$X_1 = count\ of\ deaths$$

$$X_2 = count\ of\ severe\ injuries$$

$$X_3 = count\ of\ not\ severe\ injuries$$

$$X_4 = count\ of\ collisions\ resulting\ in\ property\ damage\ only \tag{2.1}$$

2.3.6 *Statistical analysis*

2.3.6.1 Descriptive statistics

For all four outcomes, we report counts, percentages, and rates (outcomes per 1,000 meters of the road network that reported *any* outcome). To account for potential changes during the COVID-19 epidemic in 2020 (the last year of our data), we observe annual rates of MVCs resulting in property damage, injuries, severe injuries, and deaths. We calculated summary statistics of the injury severity for each period, including measures of central tendency (mean and median), dispersion (standard deviation and range), and symmetry (skewness and kurtosis). Finally, we conduct an Analysis of Variances (ANOVA) to assess if injury severity index means are statistically significantly different across the periods.

2.3.6.2 Optimized hot spot analysis

Getis-Ord Gi*, presented in *Equation 2.2,* was developed in 1992 to identify statistically significant clusters (35). We present the results of the analysis as Z scores, which indicate high/low values of severity indices that are geospatially near each other. A Gi* score near 0 indicates a random distribution of the features. We selected four four-year periods. Although MVCs are considered random events with varying frequencies over time, the Highway Safety Manual recommends 3-5 years for analyses (26).

We stratified data from rural (1,000 meters) and urban areas (300 meters) with different distance thresholds (defined as the distance at which indices would be considered neighbors). We implemented this stratification because most MVCs occur in urban areas, and we wanted to identify sites of relatively elevated risk in urban and rural areas. We classified urban areas as any areas (one km^2 spatial resolution) categorized as cities, dense towns, semi-dense towns, or peri-urban areas using the European Commission's Joint Research Center’s Global Human Settlement

Layer data. We classified rural areas as any areas classified as villages, dispersed rural areas, and uninhabited areas (23). We provide additional details on the stratification and test specifications in the *Appendix*. We present summary statistics for all outcomes for the periods in the main text and each year in the *Appendix*. Given the scale of the analysis, we show only the statistically significant hotspots (i.e., those with a Z-score equal to or greater than 1.65 indicates equal to or greater than 95% confidence). We present detailed results for 2017 to 2020 in the main text, and we give the precise results for all periods in a publicly accessible Tableau Dashboard.

Equation 2.2 Getis-Ord Gi Equation*

$$G_i^*(d) = \frac{\sum_{j=1}^{n} W_{ij}\ (d)X_j}{\sum_{j=1}^{n} X_j}$$

$$Z(G_i^*) = \frac{G_i^* - E\ (G_i^*)}{\sqrt{Var\ (G_i^*)}}$$

$$Where:$$

$$d = distance\ threshold$$

$$X_j\ = the\ injury\ severity\ index\ at\ location\ j$$

$$W_{ij}\ = the\ weight\ for\ the\ neighbor\ pair$$

2.4 Results

2.4.1 *Descriptive results – all study periods*

From 2005 to 2020, there were 147,332 MVCs in total. Of these, 87,441 occurred on national, inter-regional, and regional roads. There were 55,374 MVCs on 14 national roads, 12,070 on 11 inter-regional roads, and 19,997 on 91 regional roads. Given the high number of roads and the manual process of identifying/mapping the roads, we limited the analysis to roads with more than ten MVCs per year. We excluded 3,323 MVCs that occurred on 63 regional roads (3.8% of the data).

We present detailed results for all MVCs reporting property damage, injuries, severe injuries, and deaths in *Table 1*. There were 50,460, 51,582, 32,941, and 35,109 adverse road safety outcomes from 2005 to 2008, 2009 to 2012, 2013 to 2016, and 2017 to 2020. In three periods (2005 to 2008, 2009 to 2012, and 2013 to 2016), injuries were the largest proportion of outcomes (38.60-43.65%). Severe injuries were most common from 2017 to 2020 (43.48%). The balance of severe injuries and deaths increased over the periods; severe injuries comprised 31.43% of all outcomes from 2005 to 2008 and 43.48% of outcomes from 2017 to 2020. Similarly, deaths accounted for 10.68% of total outcomes from 2005 to 2008 and 13.87% from 2017 to 2020. To understand trends in 2020 during the COVID-19 pandemic, we report counts of each outcome annually in the *Appendix*. Upon observation, we did not find any changes in 2020 compared to other recent study years.

For all outcome rates per 1,000 meters of road, 2009 to 2012 had the highest: 8.79 MVCs; 30.30 injuries; 8.43 deaths; and 69.42 total adverse road safety events. The period from 2017 to 2020 had the highest severe injury rate (22.95).

Table 2.1 Descriptive results of road safety outcomes

Period	Measure	Motor vehicle collisions with property damage only	Injuries	Severe Injuries	Deaths	All outcomes
2005 to 2008	Count	7,059	22,149	15,862	5,390	50,460
	%	13.99%	43.89%	31.43%	10.68%	100%
	Rate*	7.12	22.35	16.01	5.44	50.93
2009 to 2012	Count	6,529	22,513	16,277	6,263	51,582
	%	12.66%	43.65%	31.56%	12.14%	100%
	Rate*	8.79	30.30	21.91	8.43	69.42
2013 to 2016	Count	4,132	12,714	11,471	4,624	32,941
	%	12.54%	38.60%	34.82%	14.04%	100%
	Rate*	5.95	18.29	16.51	6.65	47.40
2017 to 2020	Count	3,362	11,614	15,265	4,868	35,109
	%	9.58%	33.08%	43.48%	13.87%	100%
	Rate*	5.05	17.46	22.95	7.32	52.79

* Rate is the percentage % of total outcomes along the road network reporting *any* outcome. The denominator differed depending on the number of unique 100-meter locations reporting outcomes in the period. Road lengths were as follows: 2005 to 2008 – 990.8 km; 2009-2012 – 743.0 km; 2013-2015 – 695.0 km; 2017-2020 –665.1 km.

There were 9,908, 7,430, 6,950, and 6,651 unique 100-meter locations along the trunk roads with MVCs, injuries, and deaths from 2005 to 2008, 2009 to 2012, 2013 to 2016, and 2017 to 2020, respectively (*Table 2.1*). There were more 100-meter injury locations in rural areas, except from 2009 to 2012. Upon observation, most summary measures of injury severity were consistent across the periods, indicating similar patterns. Urban areas from 2009 to 2012 and 2013 to 2016 had substantially high maximum injury severity. In a one-way ANOVA, injury severity is significantly increasing over time (*F*-statistic: 15.05, *p*-value<0.05) (*Table 2.2).*

Table 2.2 Summary statistics and ANOVA results of injury severity indices

	Summary statistics						ANOVA results	
Period	**Area**	**Locations A**	**Maximum**	**Median**	**Mean**	**Standard deviation**	**F statistic**	***P*-value**
2005 to 2008	Rural	5,810	175.8	3.6	7.4	11.4	15.05	0.00*
	Urban	4,098	183.3	3.9	7.8	12.0		
	Total	9,908	183.3	3.6	7.6	11.8		
2009 to 2012	Rural	3,402	175.8	3.6	7.8	11.7		
	Urban	4,028	250.2	3.9	8.0	12.5		
	Total	7,430	250.2	3.9	8.4	13.8		
2013 to 2016	Rural	3,707	174	3.6	7.6	11.7		
	Urban	3,243	287.6	3.6	7.0	11.1		
	Total	6,950	287.6	3.6	7.3	11.2		
2017 to 2020	Rural	3,606	162	4	8.3	12.5		
	Urban	3,045	154.9	3.9	8.4	13.2		
	Total	6,651	162.0	3.9	8.4	13.1		

A. The number of unique 100-meter locations reporting MVCs, injuries, severe injuries, and deaths

*statistically significant

2.4.2 *Optimized hot spot analysis – overview for all periods*

The following section presents an overview of all periods' results and detailed results for the optimized hot spot analysis for 2017 to 2020. The other periods' national maps are in the *Appendix*. We show all results in a Tableau Dashboard at the following link: https://public.tableau.com/views/RoadInjurySeverityinGhana/Dashboard2?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link. Users can filter the dashboard by type of area, period, Z-score, and injury severity. We present detailed quantitative summaries of the hot spots (total, urban, and rural) in *Table 2.3*. Overall, the total number of hot spots ranged from a low of 365 in 2017 to 2020 to a high of 595 from 2005 to 2008). The overall proportion of hot spots to the total locations were consistent across periods (6.07-6.61% of rural 100-meter locations; 4.38-5.69% of urban 100-meter locations). In the most recent period, we identified specific clusters of injury severity (4.66% of urban areas and 6.18% of rural areas) to target for injury control.

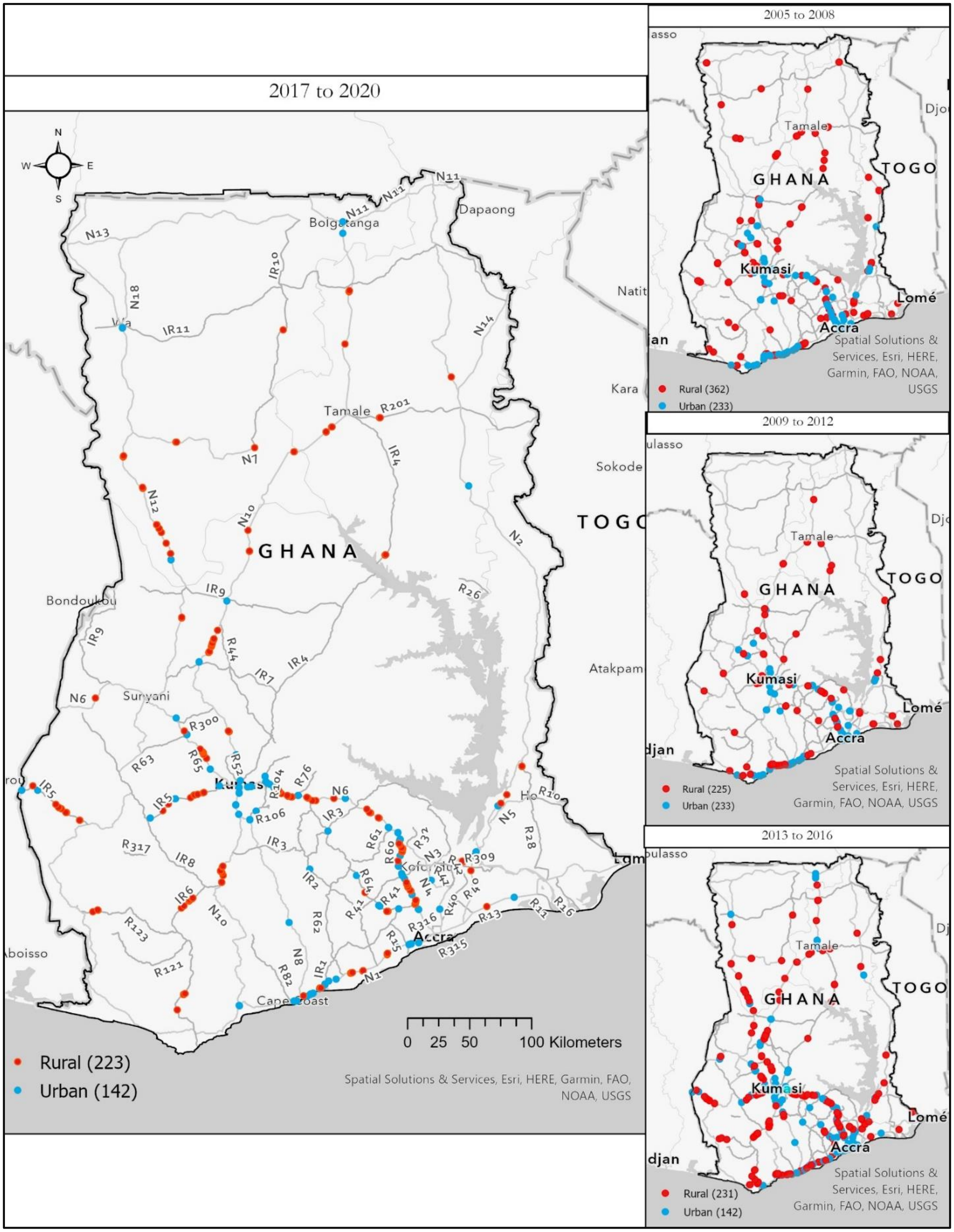
Table 2.3 Quantitative results of hot spot analysis (2017-2020)

Period	Area	Hot spot count	Locations [A]	Percentage of total locations
2005 to 2008	Rural	362	5,810	6.23%
	Urban	233	4,098	5.69%
	Total	595	9,908	6.01%
2009 to 2012	Rural	225	3,402	6.61%
	Urban	233	4,028	5.78%
	Total	458	7,430	6.16%
2013 to 2016	Rural	225	3,707	6.07%
	Urban	142	3,243	4.38%
	Total	367	6,950	5.28%
2017 to 2020	Rural	223	3,606	6.18%
	Urban	142	3,045	4.66%
	Total	365	6,651	5.49%

A. The number of unique 100-meter locations reporting MVCs, minor injuries, severe injuries, and deaths

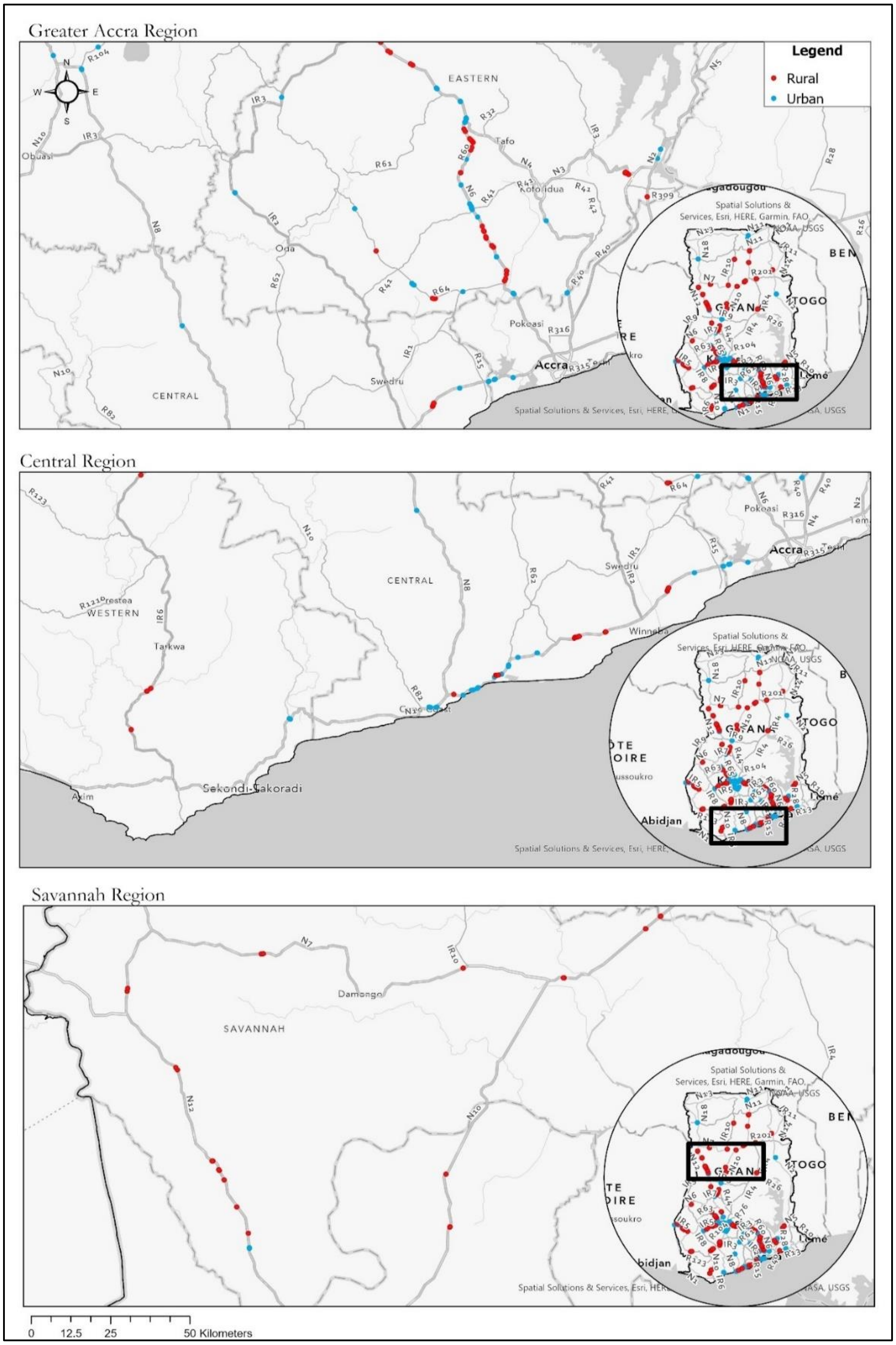
We present the results for 2017 to 2020 on a larger map and the other periods in smaller maps in *Figure 2.2*. Urban hotspots were found in the peripheral area of cities (Accra, Kumasi, and Cape Coast), often where major roads intersect. These areas often have several hot spots concentrated along the same road area. Conversely, hotspots in rural areas were more sporadic, with one or two hotspots along a major stretch of road (e.g., two hotspots along National Road 2 in the northeast of the country) and other areas that followed similar concentrated patterns. The results are strikingly similar across all periods, with some variations in the frequency of hot spots along specific roads.

Figure 2.2 Overview of urban and rural hot spots – all periods



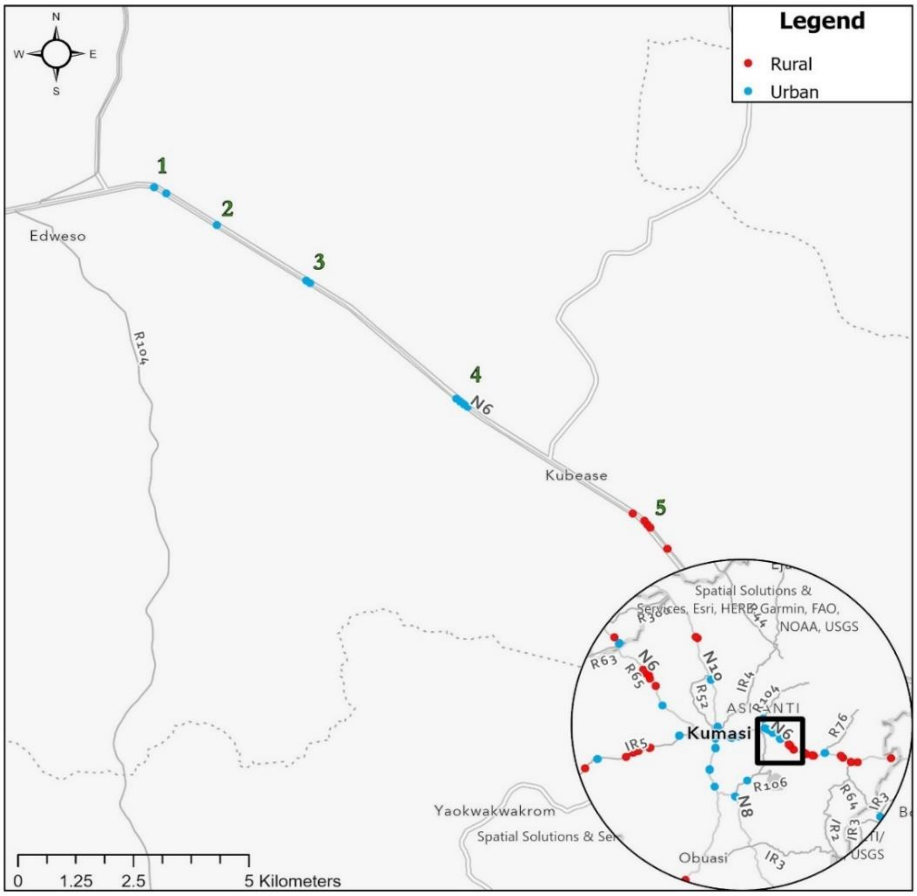
In the following maps, we highlight three regions with high numbers of concentrated hotspots to demonstrate the patterns of rural and urban clusters. The maps reveal high MVCs, injury, and severity in urban and rural areas along National Road 6 road and National Road 1. (*Figure 2.3)*. In Savannah Region, most hot spots are sporadic and spread out in rural areas.

Figure 2.3 Map of statistically significant hot spots for key regions (Greater Accra, Central, and Savannah regions) 2017 to 2020



Lastly, to demonstrate the findings' spatial specificity and utility in decision-making for decision-making and intervention targeting, we present labeled urban and rural hot spots along National Road 6 (Accra-Kumasi Road) in *Figure 2.4*. National Road 6 is a 250 km road with heavy vehicular traffic.

Figure 2.4 Demonstrative map of statistically significant hot spots along National Road 6 (Accra-Kumasi Road) (2017-2020)



Location number	Area type	Injury Severity Index	Z-score	P-value	Geocoordinates
1	Urban	2.8	3.12	0.002	6.72596244, -1.44946071
	Urban	72.2	3.12	0.002	6.72475548, -1.44705904
2	Urban	28.8	2.3	0.022	6.71833905, -1.43720666
3	Urban	12.5	8.06	0	6.70706109, -1.41972787
	Urban	154.7	8.06	0	6.70657457, -1.41896545
4	Urban	1.8	3.62	0.0003	6.68310932, -1.39036307
	Urban	103.7	2.86	0.0042	6.68256647, -1.38963976
	Urban	3	2.86	0.0042	6.68202361, -1.38891645
	Urban	1	3.61	0.0003	6.68148075, -1.38819314
5	Rural	4.3	2.58	0.01	6.65987562, -1.35588132
	Rural	16.4	2.04	0.041	6.65836438, -1.35363353
	Rural	18.2	2.04	0.041	6.65765775, -1.35306925
	Rural	58.4	2.04	0.041	6.65695112, -1.35250497
	Rural	1	2.44	0.015	6.65271135, -1.34911932

Hot spots are reported from North to South

Geocoordinates are presented as longitude and latitude for the World Geodetic System 1984 coordinate system

2.5 Discussion

This study aimed to assess spatial patterns of injury severity for four four-year periods in Ghana. We identified and mapped MVC hotspots using a well-known injury severity index. We identified specific areas (4.66% of urban areas and 6.18% of rural areas) to target for injury control. The overall numbers of all outcomes decreased over time, although severe injuries comprise a larger proportion of the total outcomes in the most recent period (2017 to 2020). Injury severity increased significantly when comparing period outcomes in aggregate, despite fewer locations of adverse outcomes in more recent periods. This data suggests limited success in reducing the overall severity of MVCs, injuries, and deaths in Ghana.

The consistency in location, trends, and typology indicates that investing in a few key areas could make a substantial difference. When looking at the findings in the aggregate, one striking finding was the consistency in the location of hotspots across the four studied periods (e.g., on National Roads 1, 4, and 6). Although there has been a significant investment into road safety measures along these roadways (e.g., multi-lanes, bypasses) which have shown some positive impacts (36, 37, 38, 39, 40), these findings suggest that they have been insufficient in altering the spatial patterns of MVCs. A related finding is consistency in hot spot types across urban and rural locations. We observed numerous hotspots concentrated on specific roads (e.g., National Road 6, National Road 1) for urban areas. Rural hotspots were often sporadic and far from one another. We found urban hot spots near trunk road intersections near major cities. Our analyses indicate that a few specific roads and sections of those roads are responsible for the most injury severity in the country. The data illustrate important trends and locations for targeted interventions in Ghana, and how rich geospatial data can be applied to develop a contextually relevant road injury prevention and control strategy.

Guided by this process, we share a few recommendations for Ghana and beyond. First, the most crucial suggestion is to urge Ghanaian implementers and policymakers to use these results for data-informed decision-making. This detailed spatial information is critical for resource planning for road safety initiatives such as road improvements and pre-hospital care capacity development (e.g., training in first aid) among policymakers (e.g., NRSA) and implementors (e.g., GHA, the National Ambulance Service) and we have highlight precise areas that they can consider (e.g., National Road 1, National Road 6). Second, we highly recommend future analyses based on this study for Ghana. In their current form, these data can be used for additional geospatial analyses, including for determining areas of high risk for vulnerable and non-vulnerable road users and for time and distance studies to understand trends between injury severity hotspots and access to health facilities or ambulance services and to answer questions on resource allocation of emergency and trauma services. Additionally, detailed geospatial data can enable quasi-experimental studies focused on the local and attributable impact of interventions in specific geographies, such as the recent paper on the effect of speed bumps on injury consequences (62). Finally, for implications beyond Ghana, in *Table 2.4* below, we describe gaps in LMICs, how our study addressed these gaps and lessons for other countries.

Table 2.4 Gaps, study approach, and lessons learned

Gap in LMICs	The current study in Ghana	Lessons learned and relevance for other LMICs
MVC data, particularly georeferenced data, are often not systematically collected or maintained (22).	Since 1991, BRRI has collected and maintained a database of all police reported MVCs, minor injuries, severe injuries, and deaths.	We recommend MVC data be collected systematically and maintained at a central level. These data should include globally standardized definitions and geospatial information to facilitate targeting key interventions.
Standardized definitions are not universally employed (e.g., death after MVC) (22).	BRRI uses death within 30 days after MVC. Police follow up to capture severity.	
Geospatial data of MVCs, injuries, severe injuries, and deaths are limited.	BRRI collect road name, meter marker, and a landmark for each MVC on major roads in Ghana that allow georeferencing.	If possible, geospatial information should be collected as geocoordinates (e.g., handheld GPS units, pin from Google Maps) to maximize georeferencing accuracy and reduce the work burden on research and program staff. Alternatively, information can be collected as road names and meter markers, and an automated geocoding procedure (such as ours) can be applied.
When geospatial data are collected, they may be underutilized if not collected as geo coordinates, as is required for many types of spatial analyses.	Our geospatial data were transformed into coordinates using an automated geocoding method. Two other studies have employed similar methods, one for severe injury collisions from 1997 to 2006 in California (52) and another for fatal MVCs in South Korean expressways from 2007 to 2009 (53).	
Research may not meet the needs of in-country implementers and decision-makers.	We co-designed the study to meet the needs of end-users (e.g., policymakers, researchers, and implementation partners). Critical decisions, such as the type of analysis (Getis-Ord Gi*), the outcome, stratification, and timeframes, were selected with in-country collaborators.	Key analytical decisions should be discussed and agreed upon with in-country decision-makers before embarking on MVC surveillance and research programs.
LMICS often use descriptive counts of adverse road safety outcomes in studies (41, 42, 43, 44, 45, 46, 47).	We used an injury severity measure to quantify the magnitude of adverse road traffic outcomes rather than descriptive reports of high counts or frequencies of collisions alone.	Studies should aim for the greatest spatial and outcome specificity to inform high-impact, targeted injury prevention and control initiatives.
Geospatial analyses are often aggregated to large geographic/administrative areas or limited to small	We identified specific 100-meter marker locations on major roads for targeted interventions rather than a region-wide area for the whole country. We	

areas (e.g., one district) (41, 43, 46, 47, 48, 49, 50, 51).	conducted a national-level analysis.	
Many road safety efforts and analyses do not consider urban and rural differences. Most road safety efforts focus on urban and higher-income populations, despite the high road traffic morbidity and mortality burden among rural, low-income individuals (52, 53, 54, 55).	We stratified distance thresholds for urban and rural areas to acknowledge differences in typologies of MVCs across the country. Stratification prevented the skewing of results to only show urban areas with high vehicles and MVCs.	We recommend that researchers consider differences in land use and population density when conducting studies to distribute road safety resources equitably.

There are a few limitations to note. First, the BRRI only captures MVCs reported by the police, leading to potential underreporting, particularly of less severe collisions with VRUs (58-61). Next, we described MVCs on national, inter-regional, and regional roads (85,493 of 147,332 total MVCs) and only on roads with more than ten MVCs yearly (96.2% of the data). We cannot generalize our findings beyond the included trunk road network. Another limitation is that we did not have exposure (traffic) data; however, stratifying our analysis by type of area and employing an injury severity index may address these limitations.

Similarly, we used a global recommendation and selected four four-year time frames. However, this shorter-term analysis does not necessarily estimate the long-term frequency, particularly given the observed regression-to-the-mean bias (26). We have addressed temporal trends in another study (Chapter three*)*. Next, this work depends on a highly accurate road network. We developed the road network by triangulating data sources, including from the GHA, the agency responsible for building and maintaining the trunk roads, increasing our confidence in the accuracy. We used the 2021 road network despite knowing that changes have been made to the roads from 2005 to 2020 (e.g., new bypasses). However, we suspect relatively few changes would not drastically affect findings. Despite these limitations, the strengths of this data remain invaluable in informing Ghanaian policy and practice. The hotspots represent locations of major public health importance regardless of limitations in the included geography or relative traffic volume.

2.6 Conclusion

In conclusion, this study demonstrates how we used MVC, injury, and death data to develop a contextually relevant understanding of high-risk areas for targeted injury prevention interventions in Ghana. We demonstrate the critical importance of collecting and maintaining geospatial road incidence data with standardized definitions to facilitate mapping and quantifying risk. By outlining lessons for LMICs, we hope to encourage future studies and data-informed decision-making to reduce the burden of road traffic injuries and deaths globally.

Chapter 3. Identifying emerging hot spots of road traffic injury severity using spatiotemporal methods: Longitudinal analyses on major roads in Ghana from 2005 to 2020

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3.1 Abstract

Although road traffic injuries and deaths have decreased globally, there is substantial national, and sub-national heterogeneity, particularly in LMICs where 90% of the world's road traffic deaths occur. Ghana is one of few countries in Africa collecting comprehensive, spatially detailed data on MVCs. This data is a critical step towards improving roadway safety, as accurate and reliable information is essential for devising targeted countermeasures to reduce injuries and deaths. Here, we analyze 16 years of police-report data using emerging hot spot analysis in ArcGIS to identify hot spots with trends of increasing injury severity (a weighted composite measure of MVCs, minor injuries, severe injuries, and deaths) along major roads in urban and rural areas of Ghana. We find injury severity index sums and minor injury counts are decreasing in Ghana while severe injury and death counts are not, indicating the latter should be the focus for road safety planning efforts. We identify 2.65% of the length of urban roads and 4.37% of the length of rural roads as areas of high risk and find that spatiotemporal patterns of severe injury and death are indistinguishable. Trends indicate that hot spots are intensifying on major roads in rural areas. Our method for evaluating spatiotemporal trends in MVC, road traffic injuries, and deaths in a LMIC includes sufficient

detail for replication and adaptation in other countries, which is useful for targeting countermeasures and tracking progress toward national and international targets.

3.2 Background

Road traffic injuries are the 8th leading cause of death for people of all ages, and the leading cause of death among children and young adults 5 to 29 years of age (5). The global incidence of road traffic injuries has increased while mortality has declined (1). Increases in road traffic injuries are due to global increases in motorized transport and VRU numbers, whereas infrastructure, legislation, and improved post-crash care have led to decreases in road traffic injury severity and associated mortality (1, 5). Despite global mortality reductions, there is substantial regional, national, and sub-national heterogeneity (1, 54). An estimated 90% of deaths and disability-adjusted life years (DALYs) from road traffic injuries occur in LMICs despite comparatively low numbers of motorized vehicles (an estimated 47% of the world's vehicles) (56, 57).

Countries have committed to reducing road traffic injuries and deaths on roads through commitments such as the *UN Sustainable Development Goal (SDG) 3.6* and the adopted resolution for the *UN Decade of Action for Road Safety 2011-2020* and the second *Decade of Action for Road Safety 2021 – 2030*, all which aim to halve the number of road traffic injuries and deaths globally (58, 59, 60). To understand whether countries are making progress toward achieving ambitious targets, it is critical to monitor and use data for road safety planning and interventions. Increasingly, countries are beginning to track detailed information on MVCs, road traffic injuries, and deaths. Since 1991, Ghana has been one of the few African countries collecting comprehensive, spatially detailed data on MVCs, road traffic injuries, and deaths, which can drastically improve the ways in which changing patterns can be identified and used to inform decision-making and implementation evaluation. More specifically, spatial statistics can identify spatiotemporal trends to allow for policymakers and public health practitioners to detect particularly high-risk areas and target road traffic injury and death prevention and control efforts. Such efforts are well aligned with a leading theory in road safety, the Safe Systems Approach, which focuses on eliminating serious road traffic injuries and fatalities by proactively and holistically addressing road system components (30, 31)

Like other LMICs, Ghana has a growing burden of road traffic injuries and deaths. The World Health Organization (WHO) estimated 7,018 deaths (27.5 deaths per 100,000 people) in 2016 (16). The cost of severe road traffic injuries and deaths was an estimated 8.2% of the country's gross domestic product in 2016 (16) . Moreover, Ghana did not reach the *UN Decade of Road Safety 2011-2020* goal to halve the number of road traffic injuries and deaths by 2020. Limited progress underscores the urgency in analyzing spatiotemporal trends, a practice commonly employed in high-resource settings. By leveraging available data, Ghana has the potential to serve as an exemplar for other countries aiming to identify trends and geographic priorities for road traffic injury prevention and control efforts.

We set out to demonstrate a method for evaluating spatiotemporal trends in MVCs, road traffic injuries, and deaths in an LMIC, and to provide sufficient detail to facilitate the replication and adaptation of these methods for other countries/agencies. We used 16 years of data (from 2005 to 2020) from Ghana. Our primary objective is to answer the research question: what are the spatiotemporal trends in patterns of road traffic injury severity in Ghana from 2005 to 2020? We used an established road traffic injury severity index that assigns greater weights based on road traffic injury severity to identify particularly unsafe and high-risk road locations. We also mapped and assessed absolute counts of MVCs, minor injuries, severe injuries, and deaths. We hypothesized that there would be statistically significant clusters of road traffic injury severity indices with distinct spatiotemporal patterns.

3.3 Methods

3.3.1 *Study area*

The African continent has the highest road traffic death rate (26.6 per 100,000 people) worldwide and has seen increases in road traffic injuries and deaths in the last three decades (5). We selected Ghana, as it is one of few countries in Africa collecting detailed and georeferenced data on each police reported MVC, road traffic injury, and death using recommended standardized definitions (i.e., anyone killed immediately or dies within 30 days of the MVC) (5, 22). This study is from 2005 to 2020. Of note, although there may have been an expected impact of COVID-19 on road safety outcomes in 2020, we decided to include this year as Ghana implemented very few COVID-19 restrictions. There was a single three-week lockdown in Kumasi and Accra from the end of March to early April 2020.

The geographical focus is on the trunk road network in Ghana, which includes national, inter-regional, and regional roadways. MVCs have been compiled electronically in the current format since 2005 (although the database started in 1991), and MVCs on the trunk road network were the ones for which geospatial information was obtained. We use the words trunk and major interchangeably. We limited the analysis to any roads reporting more than 10 MVCs a year, as many small regional roads comprise a small portion (3.8%) of the total MVCs.

3.3.2 *Data and outcomes*

Since 1991, the Ghana BRRI and Ghana Police Service collaborated to collect and maintain information on MVCs, road traffic injuries, and deaths in the National Road Traffic Accident Database for the NRSA. Trained staff from the Motor Traffic and Transport Unit of the Ghana Police Service are dispatched to each reported MVC and injury in a hospital to collect data using a standardized crash report form.

Each observation includes road and weather environment conditions (e.g., weather, road condition), vehicle characteristics (e.g., type, ownership), driver information (e.g., drinking status, age), and outcome (i.e., MVC resulting in property damage, or minor road traffic injury, or severe road traffic injury, defined as requiring hospitalization, or death within 30 days of the MVC for each road user involved. We present the variables in the *Appendix.*

BRRI store geospatial information is stored as a route number assigned by the GHA, a km marker, and a landmark such as townhall. We obtained the national road network shapefile from GHA. We also obtained complementary road network datasets from open sources including OpenStreetMap and the Humanitarian Data Exchange. We accessed the European Commission's Joint Research Center's Global Human Settlement Layer data to determine urban versus rural areas (23). This dataset presents the degree of urbanization for each one km grid by combining population density from national censuses and built-up surfaces from satellite imagery.

We used a road traffic injury severity index for each time (year) and location as our primary outcome, presented in *Equation 3.1.* There is no consensus on the best weighting method for a severity index, but the selected approach has been used in prior studies (24, 25). We included minor road traffic injury, severe road traffic injury, and death counts as secondary outcomes. Our decision to use an road traffic injury severity index is grounded in our theoretical viewpoint that we can achieve the greatest impact by focusing on severe injuries and deaths on the roads rather than trying to prevent all MVCs, as the Safe Systems Approach recommends (30, 31).

Equation 3.1 Injury severity index

$$\textit{Injury severity index} = 3 * X_1 + 1.8 * X_2 + 1.3 * X_3 + X_4$$

$$Where:$$

$$X_1 = count\ of\ deaths$$

$$X_2 \; = \; count \; of \; severe \; injuries$$

$$X_3 \; = \; count \; of \; not \; severe \; injuries$$

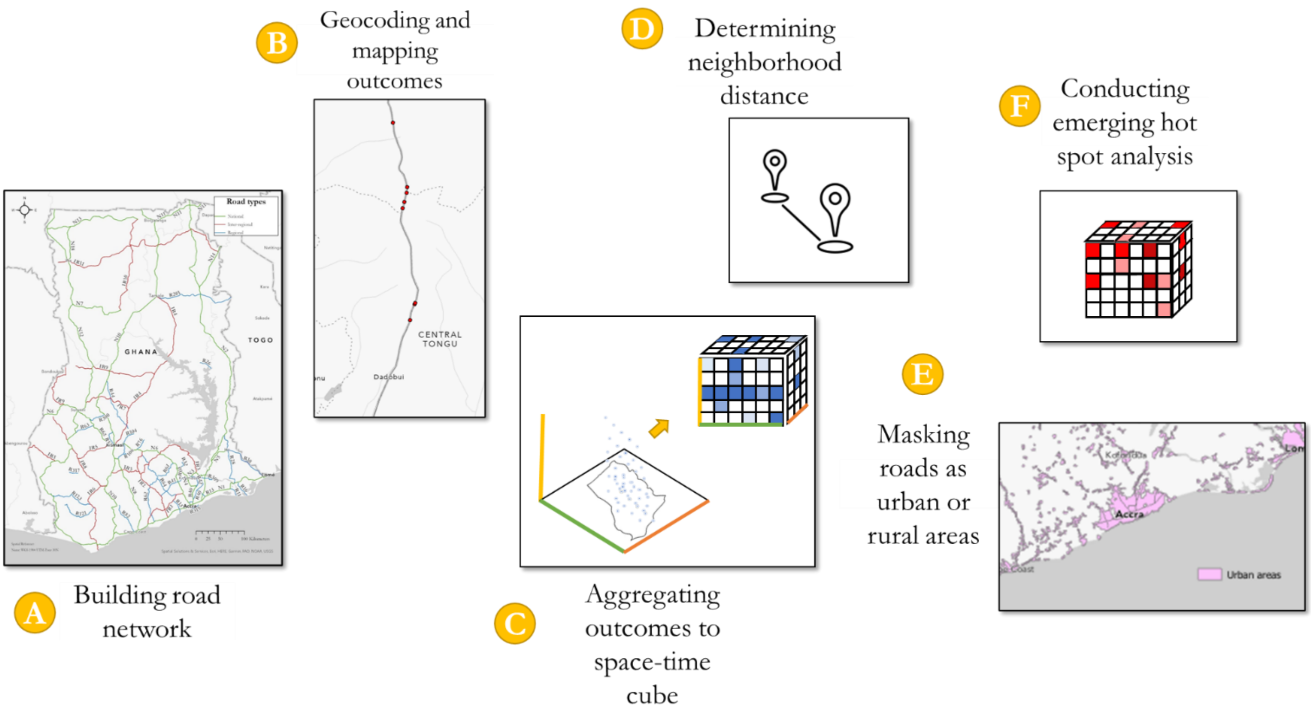
$$X_4 \; = \; count \; of \; collisions \; resulting \; in \; property \; damage \; only$$

(3.2)

3.3.3 *Data processing*

We present a summary of the processing steps in *Figure 3.1*. We provide sufficient detail on data processing and statistical analysis decisions to improve replicability and scalability of the approach to other contexts.

Figure 3.1 Data processing and statistical analysis workflow



First, we developed a road network by combining the GHA, Open Street Map, Humanitarian Data Exchange shape files, and BRRI's strip maps. We consulted experts across the BRRI and GHA to verify the accuracy of the road network by checking the start point, end point, and major curves along the road (A in *Figure 3.1*). Next, we aggregated outcomes to each unique 100-meter location along the trunk road network. We then developed an automated process in ArcGIS Pro to calculate geocoordinates (X,Y) for a projected coordinate system relevant to Ghana (World Geodetic System 1984, Universal Transverse Mercator Zone 30N). As part of this step, we quality checked the geocoordinates by comparing selecting a random subset of MVCs to manually map and verify using the

BRRI strip maps (B in *Figure 3.1*). Next, we transformed the data into a Network Common Data Form (netCDF) with a spatial resolution of 2 km using Create Space Time Cube by Aggregating Points tool in ArcGIS Pro to sum all road traffic injury severity indices within each bin and period (C in *Figure 3.1*). Our analysis included 16 years of data, the time slices, in the space-time cube. We aggregated into 2 km bins by empirically testing different spatial resolutions. We selected this resolution to balance the needs of the research question (i.e., a larger area may not be relevant for a detailed understanding of the risk on roads) and the requirements of statistical tests (i.e., sufficient power and limited zeros for time series analysis). We present the results of a series of spatial resolutions in *Table 3.1.* Adjustments to bin size did not affect results. Then, we selected the neighborhood distances (E in *Figure 3.1*) and overlaid the Global Human Settlement Layer data to determine which roads were in urban or rural areas for stratified analyses (E in *Figure 3.1*). Lastly, we conducted an Emerging Hot Spot Analysis and presented results in maps and figures (F in *Figure 3.1*). Additional details on the neighborhood distances are provided below.

Table 3.1 Space-time cube spatial resolution

Outcome	Space-time cube resolution	Number of bins	% non-zero, sparseness
Road traffic injury severity index sum for each cube	500 meters	1,605,990	24.92%
	1 km	402,420	31.72%
	2 km	50,689	40.64%
	2.5 km	44,807	43.78%
	5 km	16,330	53.91%

3.3.4 *Statistical analysis*

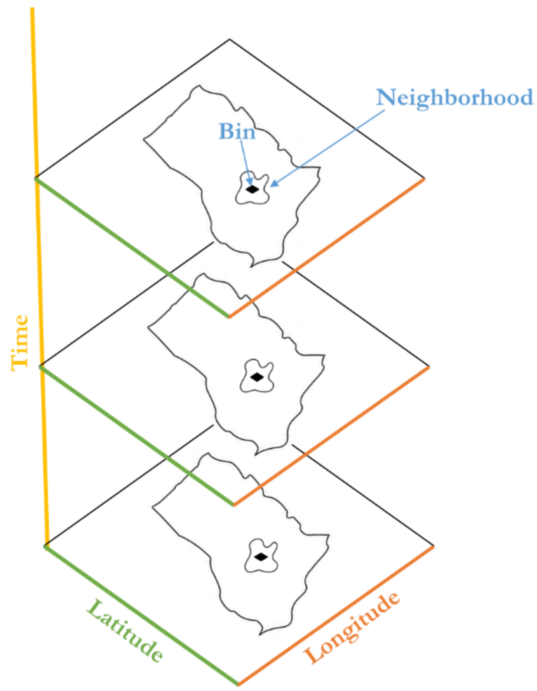
The Emerging Hot Spot Analysis is a space-time pattern mining tool that combines two statistical analyses: 1) the Getis-Ord Gi* statistic; and 2) the Mann-Kendall trend test for temporal trends. The Getis-Ord Gi* method identifies statistically significant spatial clusters

(35). Results of the analysis are presented as Z scores, which indicate high/low values of bins (in this case, the sum of road traffic injury severity indices and counts of minor road traffic injuries, severe road traffic injuries, and deaths in each bin) that are near each other. This tool considers the Z value of the bin, the Z values of surrounding bins, and the confidence levels (90%, 95%, and 99%). Large, positive Z values indicate high levels of clustering (i.e., a hotspot meaning bins with high Z scores surrounded by other bins with high Z scores), while negative Z scores indicate low values of bins surrounded by other low values of bins (i.e., a cold spot) (35). A Gi* near 0 indicates a random distribution.

A Mann-Kendall test is a non-parametric statistical method that calculates a ranking analysis of the number and value of each time interval and time order (61, 62). The test calculates values for each period in the test to derive a time-series spot pattern for each bin. The results (cluster from Getis-Ord Gi* and trend from Mann-Kendall) are then combined and categorized as new hot/cold spots, consecutive hot/cold spots, intensifying hot/cold spots, persistent hot/cold spots, diminishing hot/cold spots, oscillating hot/cold spot, historical hot/cold spot, and no detectable pattern. Definitions for each outcome are presented in the *Appendix.*

Input parameters for the Emerging Hot Spot Analysis tool include: 1) time step; 2) conceptualization of spatial relationships; and 3) polygon analysis mask. The time step determines which periods are analyzed together. Given that MVCs are considered rare and random events with varying frequencies over time, the Highway Safety Manual recommends three to five years for analyses (63). We selected 3 years as the time step, meaning five Getis-Ord Gi* results were compared in the analysis. We then decided on a conceptualization of spatial relationships. These parameters determined which bins should be considered as part of the same neighborhood. We conducted exploratory analyses and decided on the fixed distance band as the most appropriate for outcomes along the road network. A fixed distance band conceptualization means that we determine the sphere of influence or the area in which features are geographically related (the neighborhood). We selected this to evaluate statistical properties at a fixed spatial scale. In this conceptualization, neighboring bins within the distance threshold influence computations on the bin, whereas bins outside the distance do not have an influence on a bin's computations. *Figure 3.2* demonstrates the concept of a space-time cube (including the geographic components of latitude and longitude and the time component). Labels are provided for bins (in our case two km x two km bins) and neighborhoods (the area in which features are related).

Figure 3.2 Space-time cube visualization, adapted from ESRI (64)



To determine the most appropriate distance, we used the methods nearest neighbor analysis and an incremental spatial autocorrelation, for every three years for both urban and rural areas. Results indicated that the average 8-neighbor distance, recommended as a minimum for spatial analysis, was about five km for rural and two km for urban areas, with minor variations in the periods. The Global Moran's I result indicated that significant spatial autocorrelation began at about 500 meters (*Appendix).* We selected two km as the distance for urban areas and eight km as the distance for rural areas. According to geospatial experts, selecting an appropriate neighborhood based on subjective judgment from a range of density surfaces is appropriate (65). Experts also note that such decisions should be related to context of the study (i.e., relevant for road safety in Ghana) (66).

Although there were some variations in the results based on neighborhood distances (i.e., more or fewer types of outcomes), trends of clusters were consistent. For the third parameter, polygon analysis mask, we implemented a stratified analysis as most MVCs took place in dense, urban areas, whereas we sought to understand spatiotemporal associations in both urban and rural areas. Thus, we compared urban bins to urban bins and rural bins to rural bins with differing distance thresholds.

3.3.5 *Reporting*

There were 17 distinct categories of outcomes from the emerging hot spot analysis. We presented only hot spots of road traffic injury severity and counts of minor road traffic injury, severe road traffic injury, and death that fall within the following four categories (new, consecutive, intensifying, persistent) defined in *Table 3.2* below as these are the most relevant for understanding spatiotemporal patterns of road traffic injury for targeted interventions. We have presented the results below and online in a Tableau Dashboard.

Table 3.2 Categories and definitions for emerging hot spot analysis

Pattern type	Definition
New hotspot	A location that is a statistically significant for the final time step and has never been a statistically significant hotspot before.
Consecutive hotspot	A location with a single uninterrupted run of at least two statistically significant hotspot bins in the final time-step intervals. The location has never been a statistically significant hotspot before the final hotspot run, and less than 90 percent of all bins are statistically significant hotspots.
Intensifying hotspot	A location that has been a statistically significant hotspot for 90 percent of the time-step intervals, including the final time step. In

	addition, the intensity of clustering of high counts in each time step is increasing overall, which is statistically significant.
Persistent hotspot	A location that has been a statistically significant hotspot for 90 percent of the time-step intervals with no discernible trend in the intensity of clustering over time.

3.4 Results

3.4.1 *Descriptive time trends*

From 2005 to 2020, 87,441 MVCs occurred on major roads (59.3% of the 147,332 total) in Ghana. We limited the analysis to roads reporting more than 10 MVCs a year (84,118 of 87,441 MVCs; 96.2%), given that over 60 regional roads comprise less than 4% of the data. In total, BRRI reported 30,939 unique 100-meter locations along the major road network, with MVCs reporting in property damage only, minor road traffic injuries, severe road traffic injuries, and deaths. In *Table 3.3* and *Figure 3.3*, we present the annual sums of each outcome and the road traffic injury severity mean for all unique locations reporting outcomes in the analysis. We include a histogram and box plot in the *Appendix* and observe limited changes in the distribution of the road traffic injury severity index over the 16-year period. Overall, all outcomes showed decreases from 2005 to 2015, with minor road traffic injuries and property damage decreasing most dramatically. Upon observation, the sums of all outcomes seem to be increasing from 2015 to 2020.

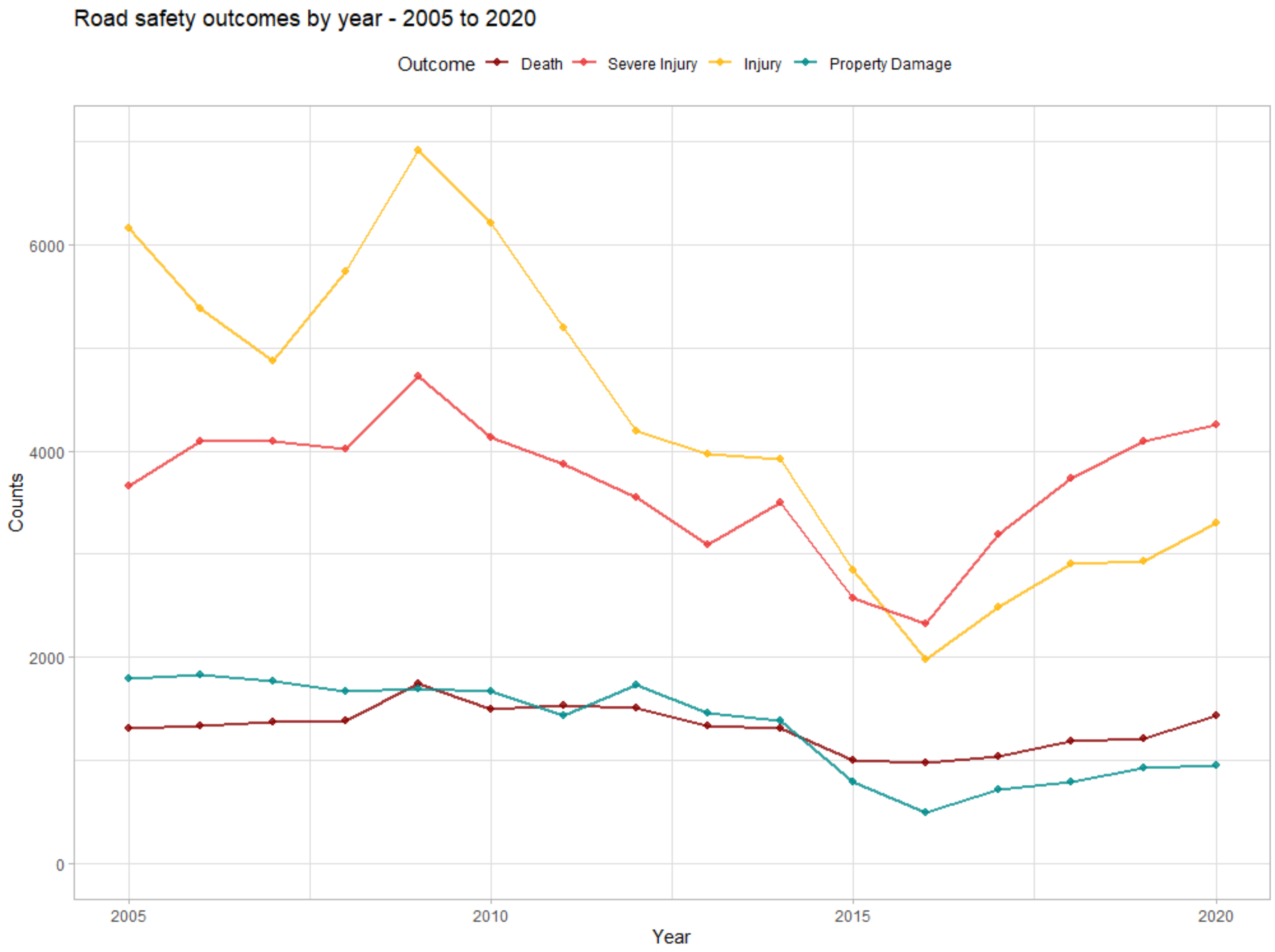
Table 3.3 Yearly sums of MVCs resulting in property damage, road traffic injuries, severe road traffic injuries, and deaths (2005-2020)

Outcome	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Property damage	1,789	1,834	1,770	1,666	1,696	1,668	1,437	1,728	1,462
Minor road traffic injuries	6,158	5,387	4,870	5,734	6,919	6,210	5,193	4,191	3,976
Severe road traffic injuries	3,658	4,088	4,091	4,025	4,724	4,133	3,870	3,550	3,090

Deaths	1,312	1,328	1,370	1,380	1,739	1,491	1,527	1,506	1,338
road traffic injury severity mean*	5.08	5.51	5.43	5.30	5.87	5.85	5.68	5.68	5.13
Outcome	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**	
Property damage	1,386	792	492	710	783	924	945	21,082	
Minor road traffic injuries	3,920	2,845	1,973	2,483	2,902	2,924	3,305	68,990	
Severe road traffic injuries	3,496	2,565	2,320	3,196	3,731	4,088	4,250	58,875	
Deaths	1,305	1,002	979	1,042	1,181	1,208	1,437	21,145	
road traffic injury severity mean*	5.44	5.18	5.62	5.30	5.71	5.88	5.75	5.52	

* For 100-meter locations reporting any MVC, minor road traffic injuries, severe road traffic injuries, and death (N=30,939 unique locations)

Figure 3.3 Yearly sums of MVCs resulting in property damage, road traffic injuries, severe road traffic injuries, and deaths from 2005 to 2020



3.4.2 *Space-time cube results*

In the space-time cube, there were 50,689 unique combinations of year and location (2 km by 2 km bins) of MVCs, minor road traffic injuries, severe road traffic injuries, and deaths across the 16 years with neighborhood distances of 2 km for urban areas and 8 for rural areas. In the space-time cube, between 2005 and 2020, the overall road traffic injuries severity and counts decreased significantly (P=0.0060 and P=0.0014, respectively), indicating overall severity and minor injuries decreased over time. However, severe road traffic injury and death counts did not decrease significantly (*P*=0.3214 and *P*=0.2241, respectively), indicating changes over time. We present these results in *Table 4.* These outcomes are consistent with the trends shown in *Figure 3* and *Table 3.*

Table 3.4 Overall trends in data (2005-2020) in space-time cube

Outcome	Overall data trend of outcome (*P*-value)
Road traffic injury severity sum[A]	Decreasing (*P*=0.0060)
Road traffic injury count[B]	Decreasing (*P*=0.0014)
Severe road traffic injury count[B]	Not significant (*P*=0.3214)
Death count[B]	Not significant (*P*=0.2241)

A. The road traffic injury severity sums of each 2 km by 2 km bin. For example, if a bin has 2 MVCs in a 3-year period, one with a road traffic injury severity of 5, another with an road traffic injury severity of 100, then the sum would be 105 for that period/bin combination. This is the value used to assess time trends.
B. This is the total count of the outcome in each period and bin. For example, if a two km by two km bin has five MVCs in a period, all resulting in deaths, the death count would be 5. This is the value used to assess time trends.

Emerging hot spot (spatio-temporal) results

In the emerging hot spot analysis, we identified a small number of high-risk clusters (shown below in *Table 3.5*). All clusters for all years are presented in a Tableau Dashboard at the following link: https://public.tableau.com/app/profile/aldina.mesic/viz/Spatio-temporaltrendsinroadtrafficinjuryinGhana2005-2020/Sheet1?publish=yes. Such information is critical for understanding which areas should be targeted for road traffic injury prevention to change Ghana's trajectory of injuries and deaths. *Figure 3.4* presents an overview of any clusters of significant trends in rural and urban areas for each outcome. Hot spots are broadly similar across outcomes. Severe injuries and deaths have more hot spots than injuries do, and the hot spots of severe injuries and deaths demonstrate nearly identical spatiotemporal patterns. We present detailed maps for each outcome and type of hot spot in the *Appendix.* We present the quantitative summaries of hot spots by type in *Table 3.5.*

Figure 3.4 Emerging hot spot analysis (2005-2020) for injury severity, minor injuries, severe injuries, and deaths

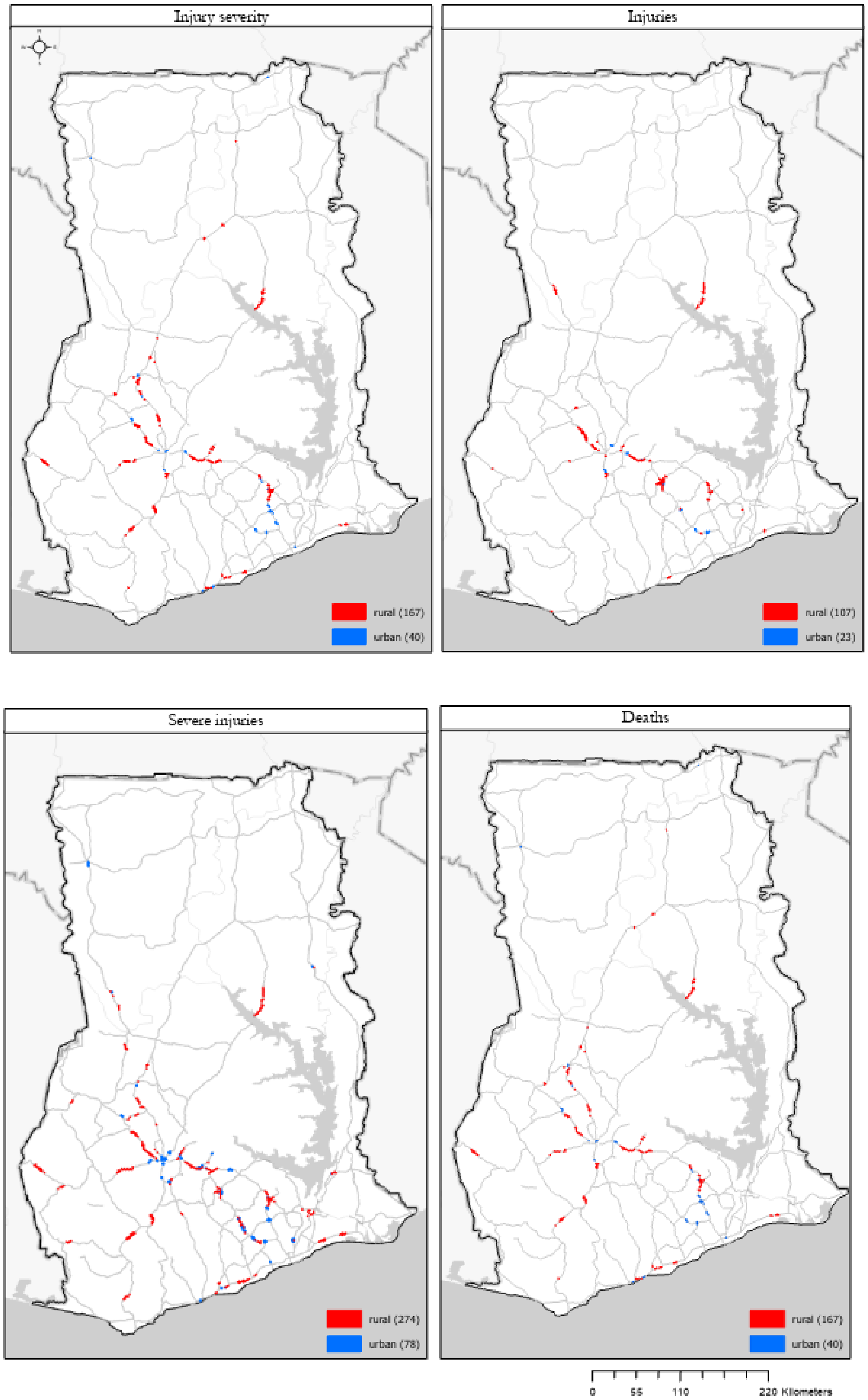


Table 3.5 Emerging hot spot results (2005-2020)

		road traffic injury severity index	road traffic injury counts	Severe road traffic injury counts	Death counts
Type of area	Category	N (%)	N (%)	N (%)	N (%)
Urban (N=1,997 bins)	No cold or hot spot trends	1,850 (92.64%)	1,912 (95.74%)	1,810 (90.64%)	1,907 (95.49%)
	New hot spot	6 (0.30%)	6 (0.30%)	19 (0.95%)	13 (0.65%)
	Consecutive hot spot	37 (1.85%)	17 (0.85%)	53 (2.65%)	24 (1.20%)
	Intensifying hot spot	3 (0.15%)	0 (0%)	1 (0.050%)	0 (0%)
	Persistent hot spot	7 (0.35%)	0 (0%)	5 (0.25%)	3 (0.15%)
Rural (N=4,299 bins)	No cold or hot spot trends	3,788 (88.11%)	4,058 (94.39%)	3,762 (87.51%)	3,925 (91.3%)
	New hot spot	35 (0.81%)	14 (32.56%)	61 (1.42%)	45 (1.04%)
	Consecutive hot spot	63 (1.47%)	28 (65.1%)	142 (3.30%)	66 (1.53%)
	Intensifying hot spot	29 (0.67%)	4 (0.09%)	19 (0.44%)	8 (0.18%)
	Persistent hot spot	96 (2.23%)	61 (1.41%)	52 (1.21%)	48 (1.12%)

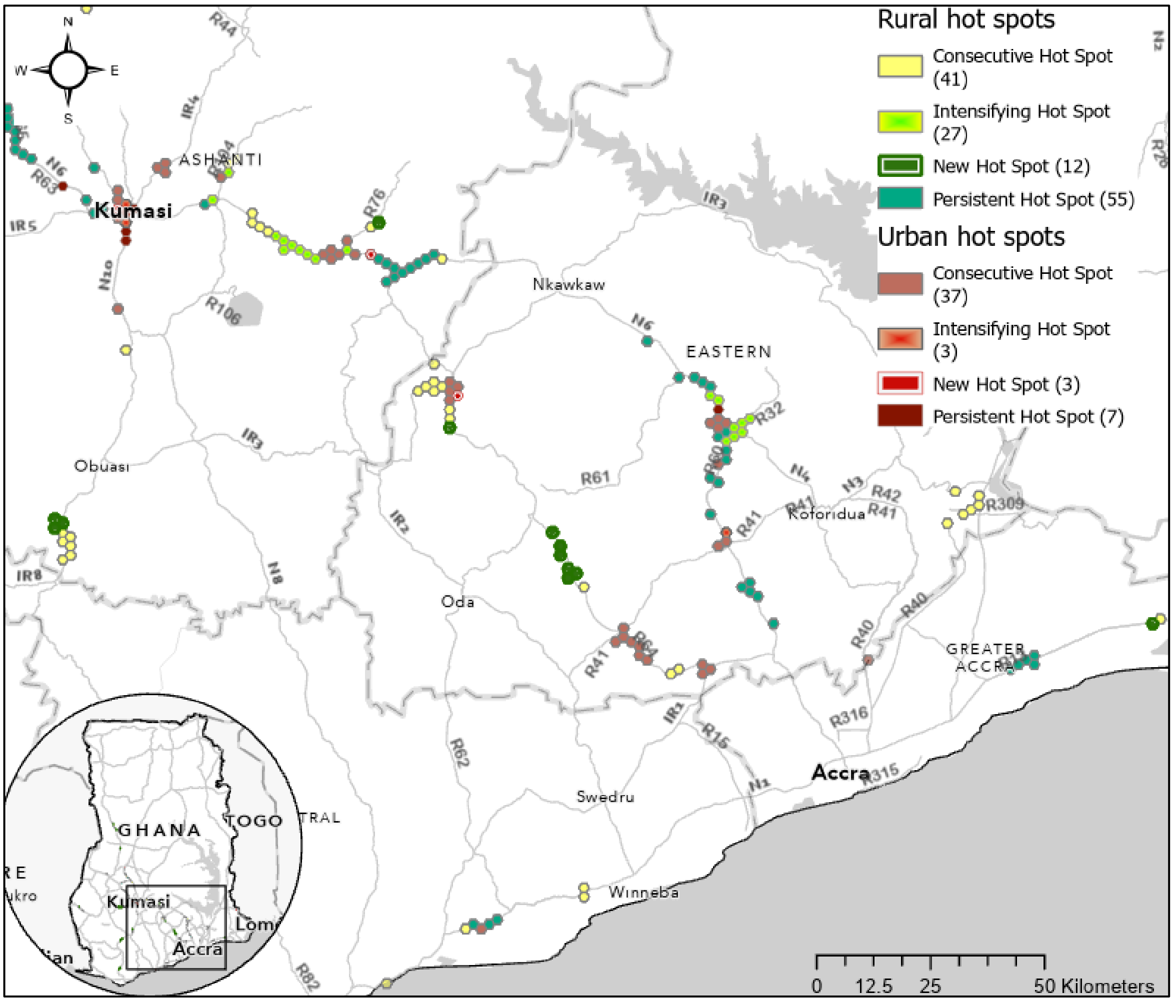
When assessing road traffic injury severity sums, we found three intensifying hot spots (90% or more of time steps being hot and hotter over time) in urban areas and 29 (0.67%) in rural areas. Two urban intensifying hot spots are found in central Kumasi, whereas another is located just north of Suhum in the Eastern Region. Several intensifying rural hot spots are found in Ejisu-Juaben District along National Road 6 and Regional Road 104 in the Ashanti region and on National Road 6 and Regional Road 32 in East Akim District in the Eastern Region (map presented in the *Appendix)*.

We found six new, defined as statistically significant in the most recent 3-year period, hot spots (0.30% of total area) in the urban areas and 35 (0.81%) in rural areas. The new urban hot spots were found in Kumasi city, east of Konongo in Asante Akim Central District, and in Mamangso in Birim North District. New rural hot spots were found all over the country were often concentrated in a specific area, such as seven new hot spots on Inter-regional Road 5 between Kumasi and Bibiani in Atwima Mponua District.

We found 37 (1.87%) consecutive hot spots (defined as a single uninterrupted run of hot time step intervals) in urban areas and 63 (1.47%) in rural areas. Consecutive urban hot spots were all found on roads linking or between Kumasi and Accra, such as National Road 6 and Regional Road 64 in Central, Eastern, and Ashanti Regions. Rural consecutive hot spots were more widespread but followed similar patterns to the other categories (i.e., several concentrated along a specific stretch of road). Lastly, we observed seven (0.35%) persistent (defined as 90% of the time steps being hot) in urban areas and 96 (2.23%) in rural areas. Most locations (87.51-95.75%) across all outcomes and area types did not have a statically significant trend.

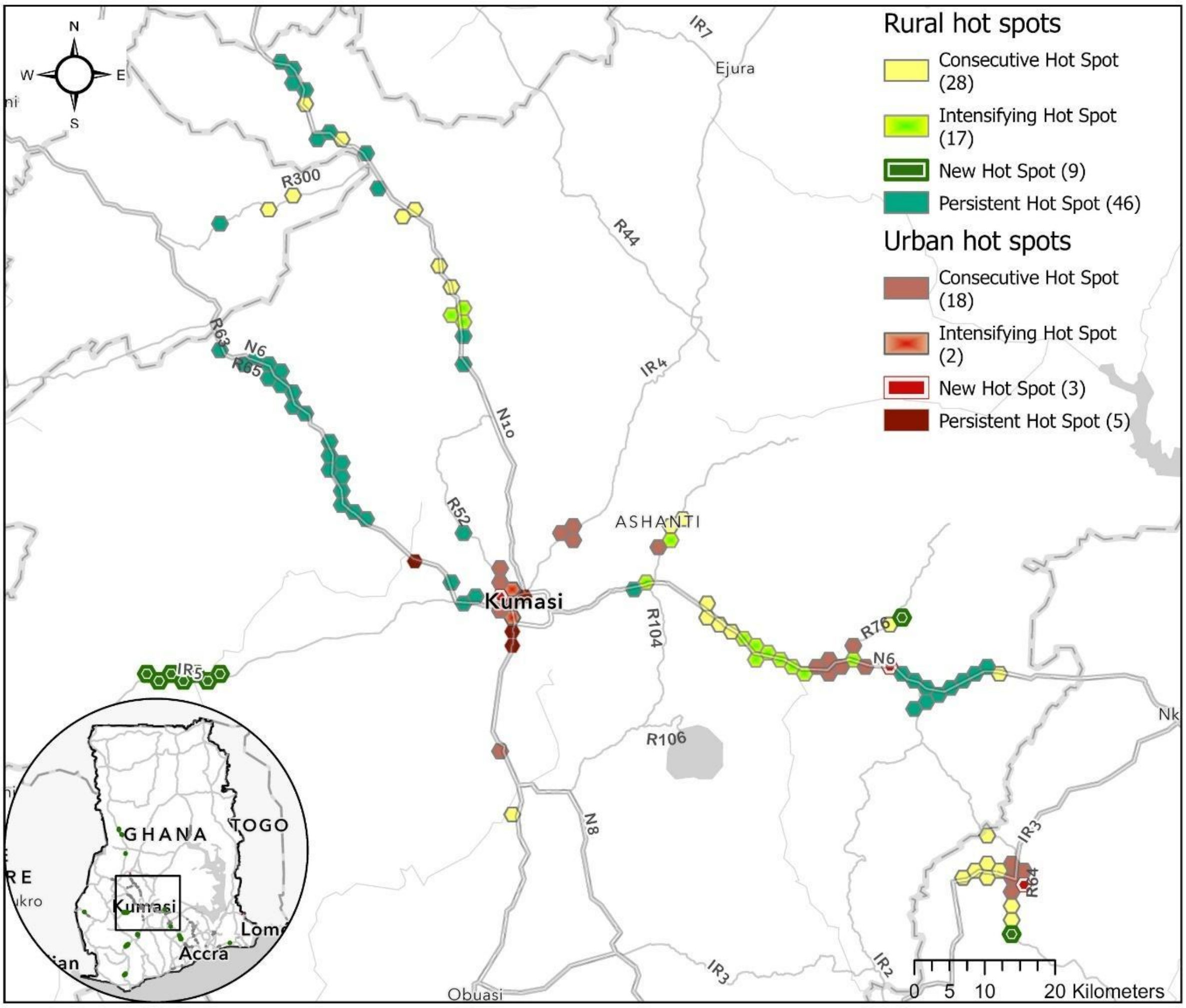
In *Figure 3.5,* we highlight a few regions with significant patterns of road traffic injury severity over the 16-year period. In Greater Accra and Eastern Region between three of Ghana’s largest cities (Accra, Kumasi, Cape Coast), there are numerous bins with trends in urban and rural areas. National Road 6, and Regional Roads 64 and 32 have several concentrated areas of high risk.

Figure 3.5 Key regions of hot spots (2005-2020)



To demonstrate the spatial specificity and utility of this analysis and output for decision-making, we present a high-resolution map of greater Kumasi in *Figure 3.6.* In this map, we have identified critical locations and information for decision-makers in the Ashanti region regarding which roads and stretches of roads are responsible for road traffic injury severity in the country over 16 years. For example, the center of Kumasi has new, intensifying, and consecutive hot spots relative to the rest of the urban areas in Ghana, indicating it is of high priority to address. National Road 6, southeast and northwest of Kumasi, show persistent and intensifying trends of hot spots.

Figure 3.6 Rural and urban hot spots in Greater Kumasi



3.5 Discussion

We conducted emerging hot spot analyses to assess clusters of road traffic injury severity over space and time in Ghana from 2005-2020. In aggregate, we find the road traffic injury severity index and minor injuries are decreasing significantly; however, severe injuries and deaths are on the rise. This may be explained by the fact that most outcomes are MVCs and minor injuries, indicating these outcomes are responsible for the overall observed decrease in the road traffic injury severity index over time. The increasing counts of severe injuries and deaths should be the focus of future road safety efforts in Ghana in accordance with the Safe Systems Approach (30, 31). Observationally, we find that all outcomes are increasing since 2015. The rapid expansion of motorized two- and three-wheelers in recent years may help explain this trend. These vehicles have altered road traffic injury trends, exacerbating the problem for VRUs (e.g., pedestrians, cyclists, and occupants of powered two-and three-wheelers) (67).

Our analysis identified a small proportion of the major roads to target for road traffic injury prevention (2.65% of major roads in urban areas; and 4.37% of major roads in urban areas) to shift increasing trends of road traffic injury severity. Specifically, we identified three specific 2 km by 2 km urban areas and 29 specific 2 km by 2 km rural areas, which are intensifying or becoming more severe hot spots over time. By using a data-driven approach which focuses the issues onto 7% of the major roads, we transform a national problem of high injuries and deaths into a more manageable and actionable issue. This highly targeted approach enables a more efficient and potentially effective deployment of scarce road safety resources, one which is needed to meet the goals of the second *Decade of Action for Road Safety 2021 – 2030*.

Trends in rural areas are particularly concerning. Studies have documented the persistent issue of road traffic injuries and deaths in these areas for decades (52, 68), and we now have data to support the urgency of the issue. Understanding the factors related to this trend, which may include land use changes, road degradation, or disparities in post-crash care, is crucial. Also, the notable differing trends in rural and urban areas support urbanization-stratified study designs, such as a recent analysis of the predictors of injury severity among motorcyclists in urban areas versus rural areas (69). Understanding and altering these temporal trends on a granular level may change the overall trajectory of road safety outcomes and progress toward national and international targets. In line with this, we would recommend that next steps of this analysis could involve a detailed analysis of characteristics for MVCs in these areas to better understand the key drivers and risk factors or to conduct this analysis among specific road users (e.g., pedestrians) or vehicles (e.g., motorcycle, motorized tricycle) types. This detailed understanding is critical for planning hazard reduction strategies for each location.

Beyond addressing existing issues, this method contributes to predicting future trends, a key distinction from related hot spot analyses. Hot spot analyses and similar spatial assessments retrospectively identify areas of high risk. This work goes beyond that by capturing both the spatial and temporal dimensions, enabling a more nuanced understanding of which areas or road users are most affected and may be experiencing deteriorating safety conditions. Advancements in technology, computing, and data (e.g., real-time electronic crash reports) could enable this method to be used frequently in real time, rather than as a periodic review of trends. Moreover, this method could be expanded for evaluations to monitor the impacts of interventions.

In this report, we applied spatiotemporal analyses to Ghana, but we have outlined our methods, model assumptions, and analytic decisions with sufficient detail to facilitate research for road safety practitioners in other countries. This method has been applied to assess pedestrian MVC locations in two cities in India (70), MVCs involving elderly people in Seoul (71), heavy vehicle MVCs in Western Australia (72), urban MVCs in China (73), and single-lane departure MVCs in North Dakota (74). To the best of our knowledge, this is one of the first attempts to understand emerging trends and geographic priorities nationally in Africa. It also underscores the importance of frequently collecting and monitoring road traffic injury and death data on a granular level, so that we can move beyond simple descriptions and identify emerging trends to guide future interventions.

For other countries in Africa and beyond that may consider similar analyses, we would recommend considering a few critical data and study design components. First, georeferenced data on MVCs, road traffic injuries, and deaths is required. This is a notable gap in LMICs and should be urgently addressed, given the disproportionate burden of road traffic injuries and deaths in these settings (22). The benefits of collecting and maintaining these data cannot be overstated, given their application for understanding areas of high risk on the roads. Next, the data must also have at least 10-time steps for this analysis to assess temporal trends. This requirement could be 10 years, months, or weeks of data depending on the timescale of interest. The data must be processed and analyzed quickly to provide real-time insights that can be translated into action. Next, given how crucial the key parameter selection is (e.g., neighborhood distance, bin size), each aspect should be discussed and decided with in-country partners to ensure the parameters and findings fit the relevant research questions. We selected small (2 km by 2 km) bins and differing neighborhood sizes for urban and rural areas to capture localized patterns of injury severity after discussions with partners. Our decision to stratify or mask the analysis by urbanization status was informed by local partners to acknowledge the dramatically different land use, population density, and infrastructure of major roads in urban and rural areas in Ghana.

This study has some limitations to note. We rely on police-reported data on MVCs, minor road traffic injuries, severe road traffic injuries, and deaths, which may be underreported, particularly for less severe outcomes. There is a notable difference between the BRRI and WHO estimates for outcomes (e.g., over 7,000 annual deaths). This discrepancy is not unique to Ghana and has been observed at different levels across countries (75, 76, 77). We have no reason to believe that this data is systematically missing (termed missing not at random), as the data collection methodology was consistent over the study. As such, we believe that this data is useful, particularly for evaluating trends over time. Second, our dataset includes 2020, when the COVID-19 pandemic occurred, which may have influenced road safety outcomes. However, in the aggregate, 2020 did not seem dramatically different from other years, and further, our analysis used 3-year time slices, so this should not have affected our results. Additionally, Ghana had very limited restrictions (one three-week lockdown in Kumasi and Accra), which we suspect did not affect results. Next, many test specifications (e.g., bin size, and neighborhood distance) are subjective. We selected these parameters by considering the research question and context to design an analysis that could arm policymakers with meaningful and specific findings for future road safety efforts.

3.6 Conclusion

Our study demonstrates how the increasing availability of georeferenced road traffic injury and death data allows for analyzing and monitoring spatiotemporal trends. Trends can inform decision-making related to injury prevention and track progress toward national and international goals and forecast future patterns.

Chapter 4. Investigating contributing factors to road traffic injury severity: A comparative study of VRUs (pedestrians, cyclists, and powered two- and three-wheeler occupants) and non-vulnerable road users in Ghana

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4.1 Abstract

In LMICs, road traffic injuries and deaths are a major public health crisis. VRUs lack external protection and bear a disproportionately high burden. We retrospectively evaluate police-reported data on each minor injury, severe injury, and death in Ghana between 2016 to 2020 to determine the impact of human, vehicle, and environmental factors on outcome severity. We compared factors affecting severe injury and mortality odds among VRUs and non-VRUs. We also performed sub-group analyses on the four VRU types commonly found in Ghana: 1) powered-two wheelers (including drivers and riders), 2) powered three-wheeler (e.g., autorickshaw) occupants, 3) cyclists, and 4) pedestrians. The analysis included 51,033 injured road users: 18,892 minor injuries, 24,200 severe injuries, and 7,450 deaths. Important factors in terms of significance and magnitude across groups included head-on collisions (VRU OR: 2.03, 95% Confidence Interval [CI]: 1.88, 2.20, non-VRU OR: 2.14, 95% CI: 2.01-2.27), collisions in rural areas or villages (VRU OR: 1.81, 95% CI: 1.71, 1.91, non-VRU: 1.30, 95% CI: 1.24, 1.37), and collisions at nighttime with no lights or the lights off (VRU OR: 1.54, 95% CI: 1.33, 1.77, non-VRU OR: 1.36, 95% CI: 1.22, 1.51). We found heterogeneity in the factors associated with injury severity depending on the road user type. Road medians were protective for non-VRUs (OR: 0.76, 95% CI: 0.69, 0.83), but not for VRUs. Commercial bus-involved collisions, and collisions at night with no lights or lights off increased the risk for powered two-wheelers and pedestrians. Passengers were at higher risk of severe injury and death compared to drivers of powered three-wheelers (OR: 1.62, 95% CI: 1.62, 1.97). Pedestrians were more likely to be injured on gravel or earth roads (OR: 1.43, 95% CI: 1.11, 1.84). The results demonstrate the importance of a context- and road-user-specific approach to injury prevention.

4.2 Introduction

Globally, road traffic injuries and deaths are an escalating public health crisis. As of 2023, road traffic injuries are the leading cause of death for children and young adults (age 5-29 years) [1] and the 6th leading cause of morbidity for all age groups [2]. Increasing motorized transportation and urbanization trends strongly indicate this burden will grow [1]. LMICs bear the bulk of the burden, with over 90% of the world's road traffic deaths [3, 4]. Although road traffic mortality has dropped globally, this progress has not been equitable [3]. Between 2013 and 2016 of 126 included LMICs, road traffic deaths increased in 87 countries and did not change in 16 [1]. It is important to understand contributing factors and influences on injury severity to effectively reduce and eliminate severe injuries and deaths on the roads. While assessing trends in the frequency of adverse road safety outcomes remain important, focusing on the most serious outcomes and factors may have a greater impact on the public health burden.

Within LMICs, over half of LMIC road traffic injury victims are VRUs, defined as those most at risk and without external protection [1, 5, 6]. VRUs include drivers and passengers of powered two- and three-wheelers, cyclists, and pedestrians. Deaths among this group are frequent, given that walking, cycling, and traveling on motorized two and three-wheelers are the most common modes of transportation in LMICs [7]. Further, an estimated 88% of the world's powered two- and three-wheelers are in LMICs, and the numbers are proliferating [8]. The expanding fleet is due to the wide availability of low-cost motorcycles [9], lower fuel consumption, increasing traffic, and an unmet transportation need, among other factors [10]. Trends indicate road safety policies often inadequately protect VRUs, and they are commonly overlooked in transportation planning, which traditionally focuses on motorized vehicles [8][11]. In response to these shortcomings, there have been calls for context-specific solutions for at-risk road user groups [1, 12]. In reviewing the prior literature of injury severity studies in Africa, we find pedestrians in Ethiopia are at higher risk of severe outcomes when struck by heavy vehicles (e.g., mini-buses, trucks), on high-speed roads and intersections, at nighttime, and with low educated drivers (78). Prior studies on motorcycles have found that speeding, driving under the influence of drugs and alcohol, not wearing a helmet, being a young driver, and violating road laws, may increase the odds of injury severity (79, 80, 81). Road class (e.g., medium speed, collector roads), weekends (versus weekdays), off-peak hours, and head-on collisions were shown to increase injury severity in Dar es Salaam (80), while two studies in Ghana found that MVCs at junctions influence severity (79, 82). Although there are some studies on these key populations, to the best of our knowledge, no studies compare the risks based on vulnerability status, or on vulnerable road-user types in Africa (67, 69, 79, 80, 81, 82, 83).

As in other LMICs, road injuries and deaths are a big issue in Ghana, with an estimated 24.9 road traffic deaths per 100,000 people, compared to 8.3 deaths per 100,000 in HICs [13, 14]. VRUs make up most of the deaths; 43% of deaths are among pedestrians, 18% among motorized two- and three-wheelers, and 3% among cyclists [1]. In contrast to other LMICs, since 1991, Ghana has been one of few countries collecting high-quality details on each motor vehicle collision (MVCs), injury, and death using the UN-recommended standardized definition [15]. Under the leadership of the NRSA, the BRRI collects police-reported data on each MVC, injury, and death. This data provides a unique opportunity to develop an understanding of factors that contribute to severe injury and death frequency and severity.

Our study is relevant and timely, given that Ghana has not met national or international targets to halve the number of deaths by 2020. While MVCs and minor injuries have decreased in the last 16 years, there has been no reduction in severe injuries or fatalities (Chapter 3). We hypothesize that stalled progress may be due to the increased severe injuries and deaths among VRUs. There are increasing numbers of motorized two- and three-wheelers (called an “aboboyaa” or a “pragya”) in Ghana, mirroring a global phenomenon. Road safety experts recently agreed that there is a research gap in the understanding of the impact caused by increasing numbers of these vehicles on the roads (84). Trends indicate that increasing numbers are shifting road traffic death patterns, as motorcycle occupant deaths comprised 2.7% of total deaths in 2001, 19% in 2014, and 34% in 2021 [16] (85).

This study aims to contribute to the understanding of injury severity risk by using existing data to 1) determine and compare the factors associated with severe injuries and deaths in Ghana from 2016 to 2020 by vulnerability status; and 2) assess the factors relevant to understanding injury severity in four categories of VRUs: powered two-wheeler occupants; powered three-wheeler occupants, cyclists, and pedestrians. This information will be critical for informing appropriate, context-specific interventions for at-risk road user groups in Ghana and other similar LMICs.

4.3 Methods

4.3.1 *Theoretical model*

The Safe Systems Approach in road safety guides our study. This approach calls for considering MVCs in the context of the systems that gave rise to them, aiming to prevent all serious road injuries and deaths by addressing all factors as appropriate, including road users, vehicles, post-collision care, roads, and speeds [17-19]. Specifically, this proactive approach requires identifying and preventing injuries and deaths before they occur by identifying and acting on the factors that affect and influence injury severity. We conducted a comparative approach of different road user types, acknowledging that factors related to vehicles, roads, and other components may have different impacts across road user types. The first comparison is between VRUs and non- VRUs. Next, we conducted a subgroup analysis of each VRU type: 1) powered two-wheeler occupants, 2) powered three-wheeler occupants, 3) cyclists, and 4) pedestrians.

As part of this work, we employ the leading framework in injury prevention, Haddon's Matrix, to understand contributing factors within three components of the epidemiological triad (host, agent, and environment [social and physical]) [20]. Our study assessed factors that fit within the host/human (these terms are interchangeable with road user), vehicle, and environmental components. In addition, we assessed additional variables that do not fit within Haddon's framework (e.g., time of day, MVC type).

4.3.2 *Study setting, data, and data processing*

We conducted this study in Ghana with five years of national data from 2016 to 2020 obtained from the BRRI. Since 1991, under the leadership of the NRSA, the BRRI and Ghana Police Service have collected detailed information on each MVC, injury, and death

(*Appendix)*. The current data collection process involves capturing information on each MVC's environment and characteristics, each vehicle involved, each driver, and any pedestrian and passenger injured or dies in the MVC. Although MVC severity has four outcomes: property damage only, minor injury, severe injury (defined as requiring transport to the hospital at the time of the MVC), and death, we only included the last three in this analysis as BRRI collected no information on unharmed passengers or pedestrians.

We conducted descriptive analyses to determine the most appropriate methods of recoding variables to avoid modeling sparse data [21]. We defined a child as under 18, the national definition [22]. An elderly individual was defined as anyone over the age of 64, as has been recommended by the UN [23]. Next, based on previous studies, we created a young driver involved indicator variable (yes/no) for any MVC with a driver under 24; this cut-off was based on a recent systematic review [24]. Lastly, we developed an indicator variable for appropriate road width (yes/no) using >=7.3 meters based on the GHA road design guide [25].

4.3.3 *Variable selection and model development*

We conducted variable selection in three stages. First, we assessed the level of missing data for each variable and excluded variables with more than 10% missing data. Next, we conducted univariate analysis (likelihood ratio tests) to determine if the inclusion of each parameter significantly improves the model fit. Lastly, we analyzed multicollinearity and removed all variables with a variance inflation factor greater than five.

4.3.4 *Statistical analysis*

We conducted analyses on an injured person level. We selected a multivariate regression using a generalized ordered logit model. To confirm that this model was appropriate, we tested the proportional odds assumption (sometimes referred to as the parallel regressions assumption), which states that the effect of an independent variable on the odds of being in a higher (or more severe, in our case) category is constant across all categories. We used graphical methods to assess the proportional odds assumption. We plotted mosaic plots of predictors versus the injury outcomes to check the distributions.

As some variables did violate the proportional odds assumption, we fit a proportional odds model, an extension of an ordered logistical model, allowing for predictors to have different effects across ordinal categories [26]. We present the equation for this model below (*Equation 4.1*). The equation indicates that coefficients $\beta 1$ and $\beta 2$ are constant for all values of the ordinal outcome (j), but that $\beta 3$ can differ across different outcome categories. We exponentiate the estimates to facilitate interpretation and present Odds Ratios (OR) and 95% Confidence Intervals (CI) for each predictor and associated outcome.

Equation 4.1: Partial proportional odds model

$$P(Yi\ >\ j) = \frac{exp\ exp\ (\alpha j\ +\ X1i\beta 1\ +\ X2i\beta 2\ +\ X3i\beta 3j)}{(1\ + exp\ (\alpha j\ +\ X1i\beta 1\ +\ X2i\beta 2\ +\ X3i\beta 3j)\ )}$$

$P(Yi\ >\ j)$: the probability that the ordinal outcome variable Y for the observation is greater than the category j given the values of the independent variables $X1, X2, X3$

j: the index for ordinal outcomes ranging from 1 to $M - 1$

M: the number of ordinal categories

αj : the cut point parameter for category j

$X1, X2, X3$: the independent variables for observation i

$\beta 1$, $\beta 2$, $\beta 3$ the regression coefficients for $X1, X2, X3$

$\beta 1$ and $\beta 2$ are constant for all values of the ordinal outcome (j), but t $\beta 3$ differs across different ordinal outcome levels.

4.5 Results

4.5.1 *Descriptive results – all road users and vulnerable versus non-vulnerable*

This study included 51,033 injured people, 30,830 non-VRUs, and 20,203 VRUs (*Table 4.1)*. Severe injuries were most common among VRUs (52% of total injuries and deaths) and all road users (47%), whereas minor injuries were most common for non-VRUs (45%). Most of those injured are men and adults, and only a small proportion of MVCs involve young drivers (<24 years).

Table 4.1 Outcome and road user-related statistics for all, non-VRUs, and VRUs

	All road users (N=51,033)		**Non-VRUs (N= 30,830)**		**VRUs (N=20,203)**	
Injury	51,033	100	30,830	100	20,203	100
Death	7,940	16	3,064	10	4,876	24
Severe injury	24,200	47	13,756	45	10,444	52
Minor injury	18,893	37	14,010	45	4,883	24
Type of road user	51,033	100	30,830	100	20,203	100
Non-vulnerable	30,830	60	30,830	100	20,203	100
Vulnerable	20,203	40	0	0	0	0
Sex	51,033	100	30,830	100	20,203	100
Male	38,284	75	22,298	72	15,986	79
Female	12,749	25	8,532	28	4,217	21
Age categories	51,033	100	30,830	100	20,203	100
Child	5,127	10	1,889	6	3,238	16
Adult	44,351	87	28,190	91	16,161	80
Elderly	1,555	3	751	2	804	4
Road user type	51,033	100	30,830	100	20,203	100
Driver	18,781	37	10,234	33	8,547	42
Passenger	23,813	47	20,596	67	3,217	16
Pedestrian	8,439	17	0	0	8,439	42
Young driver	51,033	100	30,830	100	20,203	100
Young driver involved	5225	10	1,444	5	3,781	19

Various types of vehicles were involved in crashes, which varied depending on the road user group (*Table 4.2*). For non-VRUs, most occupants were injured when in a commercial bus (53%), followed by a car (36%). For VRUs, the vehicle type indicates either which type of vehicle struck the pedestrian (20% cars, 9% commercial buses, and 5% commercial HGVs) or the powered two-or-three-wheeler that the injured person was on at the time of the MVC (55% on powered two-wheelers, 9% on powered-three-wheelers). MVCs with a single vehicle or two vehicles were equally represented across groups.

Table 4.2 Vehicle-related statistics for all, non-VRUs, and VRUs

	All road users (N=51,033)		**Non-VRUs (N= 30,830)**		**VRUs (N=20,203)**	
Vehicle type of injured	51,033	100	30,830	100	20,203	100
Car	14,931	29	10,963	36	3,968	20
Powered-two-wheeler	11,085	22	0	0	11,085	55
Powered-three-wheeler (aboboyaa, Pragya)	1,804	4	0	0	1,804	9
Bicycle	659	1	0	0	659	3
Commercial, public transport	18,003	35	16,244	53	1,759	9
Commercial heavy goods	4,551	9	3,623	12	928	5
Type of vehicle involved A	52,751	103	32,685	106	20,066	99
Car	18,605	36	13,936	45	4,669	23
Powered-two-wheeler	12,279	24	883	3	11,396	56
Powered-three-wheeler (aboboyaa, Pragya)	2,131	4	162	1	1,969	10
Commercial, public transport	19,736	39	17,704	57	2,032	10
Commercial heavy goods	6,224	12	5,172	17	1,052	5
Number of vehicles in MVC	51,033	100	30,830	100	20,203	100
1	24,286	48	14,469	47	9,817	49
2	24,463	48	14,498	47	9,965	49
3 or more	2,284	4	1,863	6	421	2
Vehicle defects	50,769	100	30,768	100	20,203	100
Any vehicle defects (e.g., brakes)	10,510	21	8,936	29	1,574	8
A. Some MVCs involved more than one vehicle, resulting in >100%.						

Most injuries and fatalities occurred during the day, on straight and flat roads, and in good clear weather (*Table 4.3*). Regarding the road surface type, most injuries occurred on tarred, good roads. Most (about 60%) injuries occurred on roads with a good shoulder and in places without a median (90-92%,). A larger share of non-VRUs were injured or killed in rural areas or villages (71%) compared to vulnerable (50%).

Table 4.3 Environmental statistics for all, non-VRUs, and VRUs

	All road users (N=51,033)		**Non-VRUs (N= 30,830)**		**VRUs (N=20,203)**	
Weather	51,030	100	30,828	100	20,202	100
Good, clear weather	42,190	83	24,939	81	17,251	85
Rain, fog, inclement conditions	8,840	17	5,889	19	2,951	15
Light conditions	51,031	100	30,830	100	20,201	100
Day time	33,355	65	20,181	65	13,174	65
Night, no lights, or night, lights off	4,656	9	3,062	10	1,594	8
Night lights on	13,020	26	7,587	25	5,433	27
Road geometry	51,023	100	30,823	100	20,200	100
Straight and flat	42,069	82	24,201	79	17,868	88
Curve, incline, or other	8,954	18	6,622	21	2,332	12
Road surface type	51,023	100	30,823	100	20,200	100
Tar, good	34,802	68	21,280	69	13,522	67
Tar, with few or many potholes	13,882	27	8,316	27	5,566	28
Gravel or earth	2,339	5	1,227	4	1,112	6
Shoulder condition	50,997	100	30,806	100	20,191	100
Good	30,648	60	19,182	62	11,466	57
Poor or overgrown	10,445	20	6,259	20	4,186	21
No shoulder	9,904	19	5,365	17	4,539	22
Road separation	50,949	100	30,800	100	20,149	100
Median	4,396	9	2,429	8	1,967	10
Surface condition	50,938	100	30,790	100	20,148	100
Dry	50,272	97	30,288	98	19,984	99
Wet/muddy	666	1	502	2	164	1
Location type	51,027	100	30,826	100	20,201	100
Intersection	45,136	88	27,714	90	17,422	86
Segment	5,891	12	3,112	10	2,779	14
Traffic control	50,947	100	30,767	100	20,180	100
Any traffic control	5,232	10	3,186	10	2,046	10
Type of area	51,033	100	30,830	100	20,203	100
Urban	19,014	37	8,934	29	10,080	50
Rural or village	32,019	63	21,896	71	10,123	50
Roadworks	51,013	100	30,819	100	20,194	100
At road works	160	0	101	0	59	0
Road width	27,026	100	17,605	100	9,421	100

Less than 7.3 meters	15,540	58	9,912	56	5,628	60

Overall, about 25% of injuries and deaths in the non-vulnerable group occurred in head-on MVCs compared to 19% in the VRU group (*Table 4.4*). Most crashes occurred on weekdays between 12-6 PM.

Table 4.4 Other collision characteristics statistics for all, non-VRUs, and VRUs

	All road users (N=51,033)		**Non-VRUs (N= 30,830)**		**VRUs (N=20,203)**	
Head-on MVC status	51,033	100	30,830	100	20,203	100
Head on MVC	11,324	22	7,554	25	3,770	19
Vehicle maneuver	50,874	100	30,805	100	20,069	100
Going ahead	46,659	92	28,231	92	18,428	92
Turning or any other non-going ahead action	4,215	8	2,574	8	1,641	8
Day of week	51,033	100	30,830	100	20,203	100
Weekend	16,096	32	9,858	32	6,238	31
Time of day	51,033	100	30,830	100	20,203	100
Afternoon (12-6 PM)	21,057	41	12,874	42	8,183	41
Evening (6 PM-12 AM)	11,505	23	6,284	20	5,221	26
Morning (6 AM-12 PM)	13,394	26	7,772	25	5,622	28
Night (12-6 AM)	5,077	10	3,900	13	1,177	6

4.5.2 *Partial proportional odds model results – VRU versus non-VRU*

In *Figures 4.2* and *4.3*, we present vulnerable and non-VRUs, respectively, including each predictor's ORs, largest to smallest. We specify which adheres to the proportional odds assumption (i.e., have one estimate for the odds of severe injury and death) and those that violate the proportional odds assumption (i.e., have two estimates - the OR from minor injury to severe injury, and the OR from a severe injury to death). Detailed results, including each OR and associated 95% CI are included in the *Appendix*.

For VRUs, we observe that some road user factors, including being an elderly road user, compared to an adult, result in 159% increased odds of severe injury and death. In contrast, children have 32% more odds of severe injury and death than adults. Compared to men, women have higher odds of severe injury than minor injury (OR: 1.12, 95% CI: 1.03, 1.22) and death than severe injury (OR: 1.6, 95% CI: 1.47, 1.75). Regarding vehicle factors, both types of commercial vehicles involved in a MVC increase the odds of severe injury and death (HGV OR: 1.72 and 95% CI: 1.49, 1.99, bus OR: 1.18 and 95% CI: 1.04, 1.32). For environmental factors, we find one factor, MVCs occurring at night with the lights off or no lights (compared to daytime) increase the injury severity significantly. Other important MVC characteristics that increase the odds of severe injury or death compared to minor injury include head-on MVCs (versus any non-head-on MVCs), MVCs occurring in rural areas or villages (versus urban areas), and those occurring in the nighttime (compared to afternoon).

Factors that decreased the odds of risk included one road user factor (young driver [under 24 years]-involved MVC); powered two- and three-wheelers; no shoulder (compared to a good shoulder); MVC on a segment (compared to an intersection); and morning MVC (compared to afternoon).

For non-VRUs (*Figure 4.3*), we similarly find that elderly individuals and children, compared to adults, and women compared to men, have higher odds of severe injury and death (ranging from an increase of 11-36%, depending on the group and outcome). Significant factors for both groups include MVCs occurring in rural area or village (compared to the urban area), and night with no lights or lights off (compared to daytime). We also find that head-on MVC status is a significant predictor of outcome severity for both. Although commercial buses and HGVs were predictors of injury severity for VRUs, only commercial buses showed a negative impact for non-VRUs, while HGV involvement was protective (OR for severe injury: 0.83 and 95% CI: 0.77, 0.90; OR for death: 0.67 and 95% CI: 0.60, 0.76). Relatedly, although the time of day of night (compared to afternoon) influenced injury severity for VRUs, this association did not hold for the non-vulnerable group. Among non-VRUs, passengers were shown to be at much greater risk for severe injury and death compared to drivers.

Factors that decreased the odds of severe outcomes for both groups included two-vehicle MVCs (compared to single-vehicle) and powered two-wheeler involvement in the MVC. For non-VRUs, medians (OR: 0.76, 95% CI: 0.69, 0.83) reduced the odds of severe injury and death, although this was not shown for VRUs.

Figure 4.2 Partial proportional odds results - VRUs

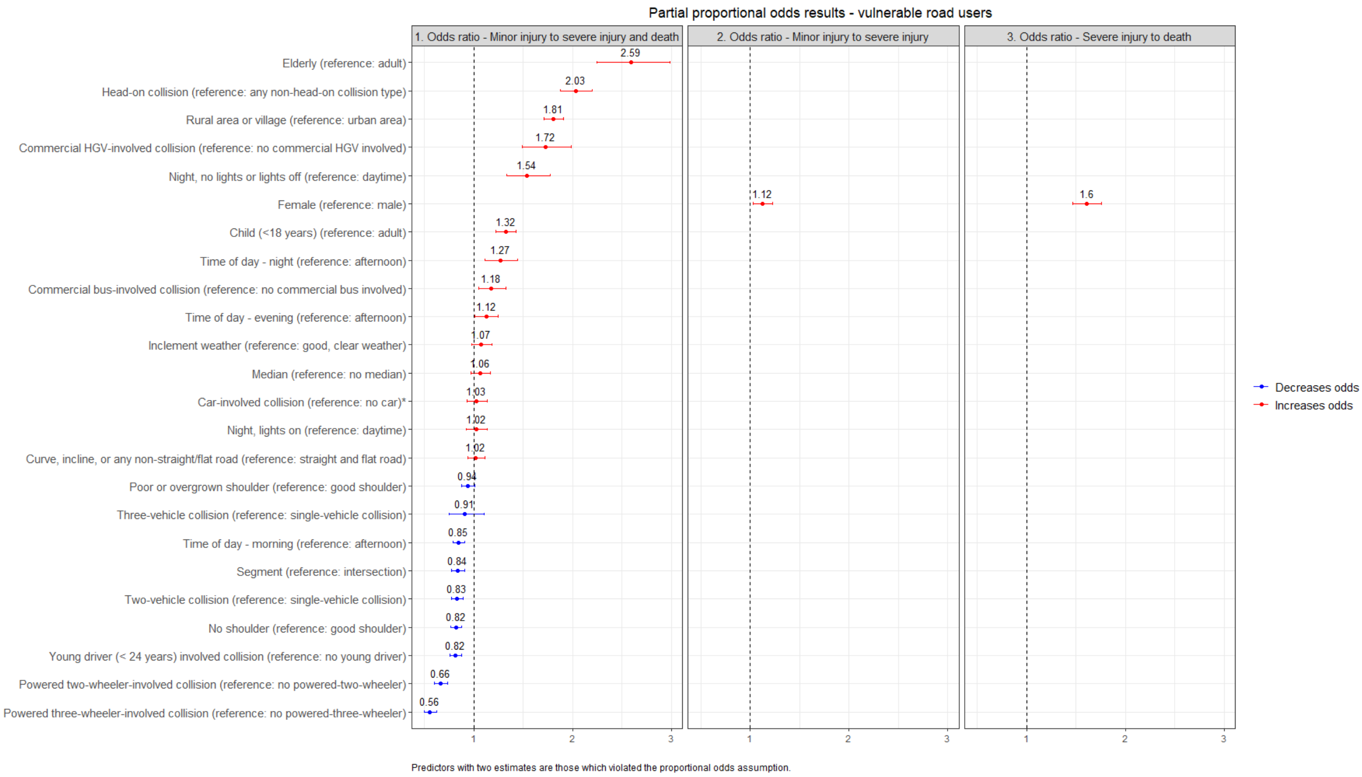
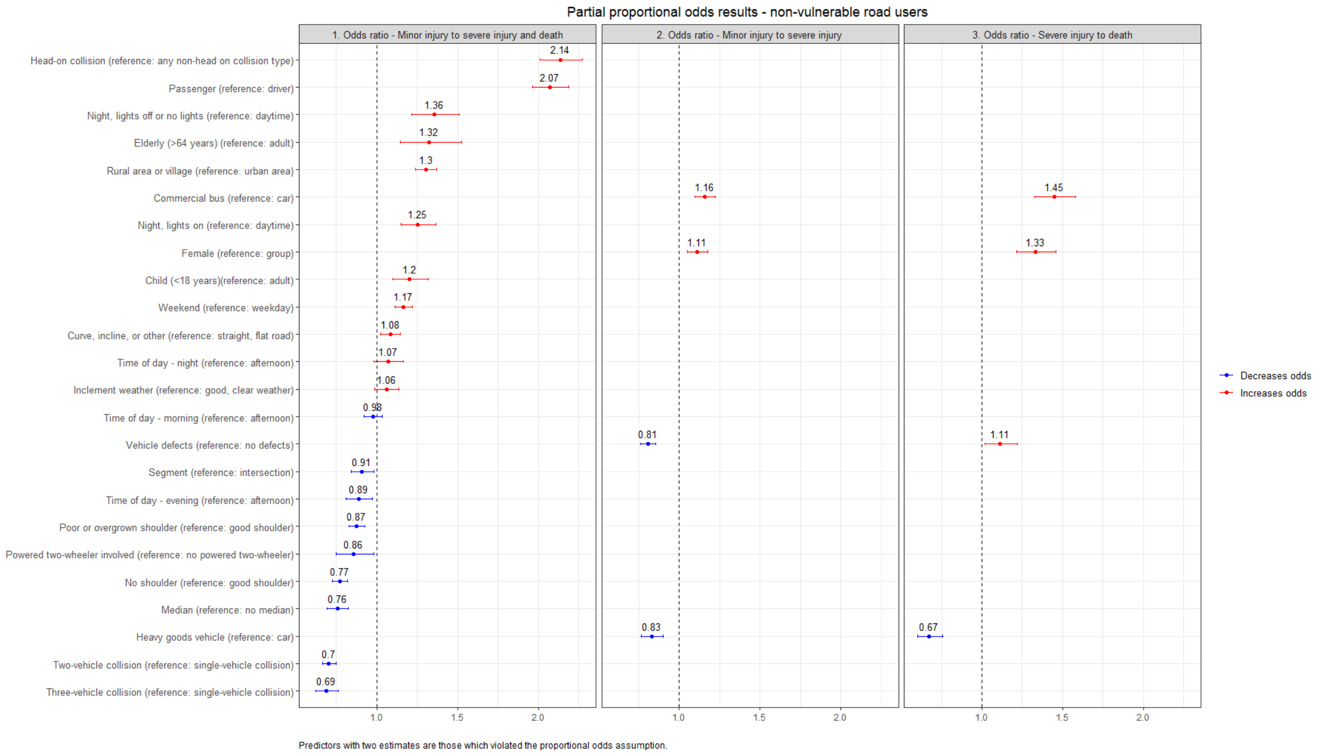


Figure 4.3 Partial proportional odds results - non-VRUs



4.5.3 *Descriptive results: VRU subgroups*

We present the detailed descriptive statistics for each VRU sub-group in the *Appendix*. Severe injuries were the most reported outcome for powered three-wheeler occupants, cyclists, and pedestrians Men were represented most often in all groups, with the highest representation among cyclists (96%). About half of the powered three-wheeler (47%) were injured compared to a quarter of those injured in a powered two-wheeler. Pedestrians were most often hit by cars, (48%) followed by public transport vehicles. Very few vehicles had any defects across any of the groups. Most of the powered two-wheeler, powered three-wheeler, and bicycle MVCs involved two vehicles.

Regarding environmental factors, most injuries occurred during good, clear weather, daytime, on straight/flat roads, and at intersections. Most injuries occurred on good, tarred roads with good shoulders. We observed an equal distribution of injuries and deaths in urban and rural areas or villages. Most injuries and deaths occurred on weekends, in the afternoon, and while the vehicle was going ahead (compared to turning, overtaking or any non-going ahead movement). Head-on MVCs comprised 33% of powered two-wheeler injuries and deaths and 27% of powered three-wheeler injuries and deaths.

4.5.4 *Partial proportional odds results – VRU subgroups*

Table 4.5 presents the significant results, including their ORs and 95% CIs for each subgroup. We include detailed plots for each subgroup in the *Appendix*.

Table 4.5 Significant predictors of injury severity – VRU sub-groups

Variable (reference group)	**Powered two-wheeler occupants (N=9,543)**		**Powered three-wheeler (aboboyaa, pragya) occupants (N=1,596)**		**Cyclists (N=625)**		**Pedestrians (N=8,439)**	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
Road user risk factors								
Elderly (reference: adult)	2.57	1.82, 3.63	2.43	1.08, 5.47	3.21	1.65, 6.25	2.55	2.15, 3.03
Child (reference: adult)							1.40	1.27, 1.54
Woman (reference: man)							0.69	0.63, 0.75
Passenger (reference: driver)			1.62	1.33, 1.97				
Young driver involved MVC (reference: no young driver)	0.77	0.70, 0.84						
Vehicle factors								
Two vehicle MVC (reference: single-vehicle MVC)			0.61	0.48, 0.78	6.07	1.69, 21.71	0.73	0.61, 0.89
Three vehicle MVC (reference: single-vehicle MVC)	1.67	1.27, 2.19	0.40	0.22, 0.73			0.56	0.38, 0.82
Motorcycle-involved							0.67 *	0.60, 0.75
Tricycle-involved					0.09	0.01, 0.94	0.69 *	0.52, 0.92
Commercial bus-involved	1.48	1.09, 2.00					1.16 *	1.04, 1.30
Commercial heavy goods vehicle-involved							1.87 *	1.62, 21.7
Vehicle defects (reference: no defects)	1.39	1.17, 1.64					0.88 *	0.79, 0.99
Environment factors								
Night no lights or lights off (reference: daytime)	1.47	1.21, 1.79					1.54	1.22, 1.95
Night, lights off (reference: daytime)							1.20	1.02, 1.42

Gravel or earth road (reference: tar, good road)	0.89	0.80, 0.99					1.43	1.11, 1.84
Tar with few or many potholes (reference: tar, good road)	0.85	0.77, 0.94						
Intersection	0.79	0.71, 0.88						
No shoulder			0.67	0.53, 0.84			0.85	0.75, 0.95
Other MVC factors								
Head on MVC	2.14	1.96, 2.34						
Turning or any non-going ahead action	1.33	1.17, 1.52						
Rural area of village (reference: urban)	1.76	1.62, 1.92			1.57	1.15, 2.15	1.99	1.82, 2.17
Time of day – morning (reference: afternoon)					0.60	0.41, 0.89		
Time of day – evening (reference: afternoon)	1.41	1.21, 1.64						
Time of day – night (reference: afternoon)	1.58	1.30, 1.93						
* This variable refers to which vehicle struck the passenger. The reference group is car.								

4.6 Discussion

The results from our study demonstrate the importance of a context- and road-user-specific approach to injury prevention. In our primary analysis of VRUs and non-VRUs, we find some notable similarities for human-level factors (e.g., being elderly, a woman), vehicle factors (e.g., commercial bus involvement), and environment/collision factors (e.g., head-on MVCs, rural or village MVCs, and MVCs involving no lights or with lights off). However, we also find some differences, such as the protective effect of medians for non-VRUs but not VRUs. In our secondary analysis of VRU subgroups, we observe only one significant factor associated with injury across groups (i.e., being elderly). Next, we discuss how these results compare to prior studies assessing Africa's context-specific and multi-level injury and crash severity factors.

First, women, the elderly, and children were at higher risk of severe injury and death for several groups. The higher risk among women is at odds with prior studies in Africa, which found that being male [27-29] is a crucial risk factor for increased odds of death. Interestingly, although women and the elderly are much less represented in the injured population, our results indicate that their outcomes tend to be more severe, which should prompt targeted road safety initiatives for these groups to reduce severity. We do not expect this result to be related to under-reporting given the data collection procedures. Unsurprisingly, occupants of motorized two-wheelers and pedestrians fare worse for risk of death [27, 28, 30-33] and severe injury outcomes [34]. We found that a young driver status was a protective factor for all VRUs and motorized two-wheeler occupants, which is at odds with one prior study [35].

On vehicle factors, we found that bus involved MVCs increase the risk and are highlighted as an urgent issue in Ghana [28]. Two prior studies in Ethiopia have observed the importance of buses and minibuses to injury severity [27, 39]. Environmental factors did not always influence crashes as expected, suggesting that road user behavior may play a larger role in injury severity. Drivers may drive more recklessly (e.g., speeding, hazardous overtaking) on straight, flat, good roads in the daytime and during clear weather, increasing the risk of severe injury and death as seen in prior studies [28, 29, 32][35, 40] as compared to difficult driving conditions when they may be more cautious. Interestingly, roads made of gravel or dirt for pedestrians substantially increased the odds of severe outcomes. Pavement types play an important role in injury severity due to the secondary impacts (86). One study of VRUs in the United Kingdom found that 54% of head injuries could be attributed to the contact with the road or ground, rather than the impact with the vehicle itself (87). This observed association may be a proxy for a lack of pedestrian infrastructure (e.g., sidewalks) or lighting, which may be more commonly found on asphalt roads.

We provide some key recommendations for Ghanaian implementers to ensure that this study informs context-specific and appropriate interventions. We recommend some key issues to improve outcomes for all, alongside a more targeted approach to severe injury and death for specific VRU types. First, specific road users (e.g., elderly people) are shown to be consistently at higher risk, warranting additional efforts and implementation of evidence-based interventions for this key population (88). In terms of environmental and MVC factors, policies addressing the risk of head-on MVCs are needed, including building medians and shoulders, installing rumble strips, enforcing road safety laws (e.g., drink/driving enforcement), and lowering the speed limit [41, 42]. Reducing MVCs occurring in rural areas or villages is also of high priority. This finding is consistent with our prior spatiotemporal analyses, which show an alarming growth in the frequency and intensity of MVCs, injuries, and deaths on major roads in rural areas of Ghana (Chapter 3). One prior study in Ghana looked at crash severity correlates for powered two-wheelers and found differences in predictors in urban and rural areas (69). We would urge researchers to conduct future studies with stratification based on urbanization, while implementors should consider interventions tailored to the different land use and population patterns of urban and rural parts of Ghana.

We highlight a few factors that warrant further exploration for specific VRU types. For powered two-wheeler occupants, three significant factors associated with increased risk were related to nighttime (e.g., evening, night, no lights), indicating that improving nighttime infrastructure for motorcycles and increasing enforcement to prevent excessive and inappropriate driving may be warranted. We also observed that vehicle defects impacted this group, although not others, raising questions about the quality and roadworthiness of the powered two-wheelers. For powered three-wheelers, we found that passengers were at higher risk, which may speak to a lack of helmets or seatbelts. We are not familiar with studies quantifying passenger helmet use on powered three-wheelers, but a recent study in Tamale found that 1.2% of passengers of motorcycles used helmets, compared to 34.2% of drivers [43]. For pedestrians, we recommend limiting interactions between commercial vehicles and pedestrians and separating these road users by constructing sidewalks and footbridges. We echo prior calls for separating VRUs on Ghanaian roads (89). Beyond these factors, there is a greater need to understand the interactions between VRU groups in Ghana. Although several studies have evaluated the risks to motorcyclists [16, 44, 45], few have considered their impact on pedestrian injuries and deaths in Ghana or, more broadly [46].

Our study is subject to limitations. First, as noted, we were limited by the data available, which influenced our decision to conduct this study on the outcomes of minor injury, severe injury, and death among injured persons. We could not assess uninjured road users or specific variables, such as economic or educational status, which have been shown to have an impact in Africa [36, 37]), or helmet use, an essential factor in prior studies [38]. However, we have utilized a rich data source (one of the longest-standing MVC datasets in Africa) and demonstrated the richness of these data. Second, our study is affected by key decisions made during the data processing (e.g., cut-offs for the young drivers, age categories) and statistical analysis steps (i.e., model diagnostics for partial proportional odds models). However, we based these decisions on best practices and prior literature, increasing our confidence in this work [26, 50]. One of the notable strengths of this work is our application of a partial proportional odds model, which tests a fundamental assumption (the proportional odds assumption) of ordinal logistic regression. Prior studies of injury severity in Africa have used multinomial logistic regression [27-29, 32, 35, 40, 44], ignoring outcomes' ordinal nature. In contrast, others have used ordinal logistic regression, which may have predictors which violate the required proportional odds assumption [36, 39, 51]. We are only aware of one application of the proportional odds model to road safety in Ghana [16] and believe that applying this innovative and rigorous approach is a strength of this study.

4.7 Conclusion

We recommend that policymakers and implementers focus on factors associated with injury severity that may affect several road user groups, such as the increased risk related to being elderly, MVCs that are head-on, in rural areas or villages, and at nighttime with the lights off or no lights. Targeted interventions for each sub-group could include improving interventions related to nighttime risks (e.g., lighting, enforcement) for powered two-wheelers, addressing heightened risks for passengers of powered three-wheelers, and improving infrastructure (i.e., on gravel roads, to separate pedestrians and commercial drivers) for pedestrians.

Chapter 5. "We are pleading for the government to do more": road user perspectives on the magnitude, contributing factors, and potential solutions to road traffic injuries and deaths in Ghana.

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5.1 Abstract

Background: RTCs, injuries, and deaths disproportionately impact Ghana and other LMICs. This study aims to explore road user perspectives on the magnitude, contributing factors, and solutions of road traffic collisions, injuries, and outcomes.

Methods: We designed a qualitative study of 24 in-depth interviews (IDIs) with 14 VRUs (pedestrians, occupants of powered 2- and 3-wheelers, cyclists), and ten non-VRUs in four high-risk areas identified through national georeferenced crash data in Ghana in November 2022. We used a mixed deductive (direct content analysis) and inductive (interpretive phenomenological analysis) approach. For the direct content analysis, a priori categories were developed using Haddon's matrix and included human, vehicle, socioeconomic environment, and physical environment factors that road users perceive as contributing factors to collisions, injuries, and deaths, and the potential solutions that fit into each of those categories. We used inductive analysis to identify emerging themes.

Results: Participants described frequent and distressing experiences with collisions. Participants most frequently described contributing factors, implementation gaps, and potential solutions within the human-level domain of Haddon's framework. Implementation

gaps included limited enforcement in particular locations or specific times (e.g., at night), road users needing to obey safety laws despite enforcement, and the low quality of the existing infrastructure interventions. In addition, participants expressed that they felt neglected and ignored by road safety decision-makers.

Conclusion: This research highlights the importance of community input for successful road safety policies in Ghana and other LMICs. It underscores the gravity of this public health crisis, urging increased government support. We recommend collaborating with communities to adapt current interventions, including speed calming measures, footbridges, and police enforcement efforts, and introduce new measures that meet local needs.

5.2 Introduction

Community engagement plays a pivotal role in global health and is widely believed to positively impact health and contribute to the reduction of inequalities (90, 91, 92). Participation is regarded as both a means to achieve the objectives of health programs efficiently and effectively, and as an end in itself, empowering communities to take control of their own health and development (91, 93). Since 1987, the WHO has emphasized the importance of community participation as a novel approach to reducing road traffic injuries and deaths. They assert that national-level decisions for road safety are more likely to be efficiently implemented with the backing of individuals and local communities (90, 94). Participation may help ensure that interventions address the population's needs, and draws upon local knowledge and priorities for greater effectiveness (95). Although there is a staggering burden of road traffic injuries and deaths, particularly in LMICs (1, 5), community participation in injury prevention initiatives remains insufficient (5, 96, 97). Among the reasons contributing to a lack of community participation, two prominent factors include limited resources for injury prevention and top-down approaches to decision-making (97, 98, 99).

Providing communities with an opportunity to share their experiences and perceptions on road traffic injuries and deaths is an important method of engagement. However, in LMICs, qualitative studies on this subject are scarce. A recent scoping review identified only 37 such studies published between 2003 and 2017 (100). Based on this study and our literature review, we believe that only ten of these studies have been conducted in Africa, although such work could ensure that interventions meet the needs of the population (101, 102, 103, 104, 105, 106, 107, 108, 109, 110). Five studies focused on contributing factors to collisions or injuries and reported themes relating to risky road user behavior such as drink-driving among motorbike taxis (104), drug use among commercial drivers (110), jaywalking among pedestrians (101, 106), and unsafe driving among motorists (102, 109). Higher level factors included poor road conditions and traffic signs (110), narrow roadways (101), traffic congestion limiting access to post-crash care (107), and corruption/lack of enforcement (102, 104). Only one study focused on community engagement for road safety intervention planning by engaging participants to share their views on footbridges. Participants in Dar es Salaam, Tanzania spoke highly and positively on citizen participation and involvement in the design and plan of road safety interventions. They suggested ways to improve footbridges by addressing the proliferation of socioeconomic activities in proximity, crowding, lack of lights at night, and the infrastructure design components which requires a certain level of fitness (106).

The importance of qualitative research in this context is clear. As Roberts (1997) emphasizes, "without an understanding of the lives and lay expertise of those on the receiving end of our well-meaning efforts, we risk ineffective, or worse, intrusive and harmful interventions" (111). Quantitative studies, while valuable, might not fully capture the contextual factors that could make injuries more likely. To understand these factors and plan effective interventions to address those factors, the need for a deeper, qualitative understanding is paramount.

The real-world implications of this research gap are evident when we look at specific contexts, such as Ghana, a lower-middle-income country grappling with a high burden of injuries and deaths. The country experiences an estimated 24.9 road traffic fatalities per 100,000 people, in stark contrast to the 8.3 per 100,000 observed in HICs (5, 16). Yet, there is a dearth of literature on road users' perspectives on road traffic injuries and deaths. While some studies have been conducted – for example, with 26 pedestrians in Krobo (101), 20 commercial drivers in Greater Accra (102) and 13 collision survivors in Accra (103)– they primarily focus on understanding factors contributing to crashes and injuries or the experiences of crash survivors, and as noted before, do not focus on road users' involvement in the ideation, planning, or implementation of road safety interventions. This is worrying given indications of both public dissatisfaction with the existing interventions and with the lack of necessary measures elsewhere (112, 113). Bridging this gap in the literature is of growing importance considering the outcry regarding the extent and reach of road safety initiatives nationwide, coupled with the potential benefits of community participation.

This qualitative work aimed to fill this research gap by exploring the perceptions of road users in high-risk areas along national roads on crucial issues in road safety. Specifically, we aimed to generate contextual insights with the following guiding research questions:

1. What are road users' perceptions of the magnitude of RTCs, injuries, and deaths in Ghana?
2. Which factors contribute to road safety issues?

3. What are the current successes, gaps, and potential solutions?

We leveraged participatory research methods and included individuals rarely represented in road safety literature and decision-making to better align population needs and road safety interventions. By involving the community, the government can effectively implement thoughtful policies in areas where they are most needed and will have the highest potential success.

5.2.1 *Study setting*

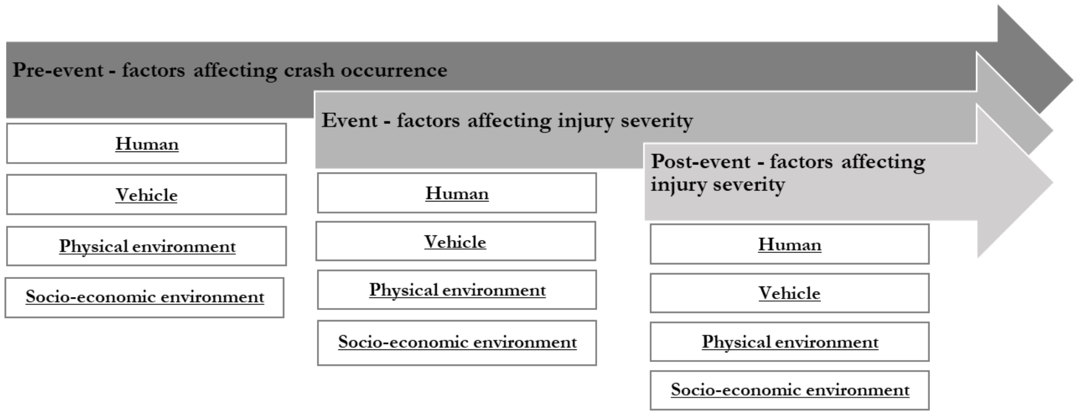
We conducted a qualitative study with road users from November 2022 to December 2022 in Ghana. This study is part of a multi-year project with the Ghana NRSA, the BRRI, the Kwame Nkrumah University of Science and Technology, and the University of Washington aimed at identifying spatial and spatiotemporal trends in collisions, injuries, and deaths along major roads in Ghana, assessing factors associated with injury severity, and conducting natural experiment studies to determine the effect of road safety interventions.. This work aims to maximize the successful implementation of interventions by evaluating research questions among a population of road users.

This study was conducted in four statistically significant crash clusters (termed hot spots) of injury severity from 2017-2020 on national roads using the nationally representative and georeferenced BRRI database (*publication forthcoming*). We purposively selected locations based on urban/rural status, traffic patterns, and recommendations from in-country partners. We selected locations to capture urban and rural views and engage participants in the Northern Region, which has unique traffic patterns (e.g., high powered two- and three-wheeler volumes) and a historically marginalized population.

5.2.2 *Approach*

This work emerges from an interpretive perspective, which sees the world as constructed and interpreted by individuals (114). We did not seek to understand objective truths about the causes and solutions of collisions, injuries, and deaths to apply universally. Instead, we aimed to understand road users' perceptions and experiences in space and time (e.g., a high-risk area). In line with this perspective, the study was conducted in a natural setting (roadside) (114)A mixed deductive-inductive approach guided this study. For the deductive component, the theoretical framework used was Haddon's Matrix (29). The framework has been widely applied in injury prevention and control. It categorizes factors affecting collision and injury occurrence into four domains, including host (human factors), agent (vehicle factors), and environment (physical and socioeconomic), and three phases (pre-event phase, event phase, and post-event phase). Recently, the matrix has expanded to include implementation considerations (115). We based additional questions in the interview on implementation science constructs from the Consolidated Framework from Implementation Research (CFIR) (116, 117). We incorporated the following constructs from CFIR: relative advantage, adaptability, intervention source, and cost to assess participants' perspectives on existing interventions and to understand their views on the rationale behind the government's decision to pursue them.

Figure 5.1 Haddon's Matrix



Given limitations on who and what may be represented in this framework, we allowed for emergent themes (i.e., an inductive approach) through an interpretive phenomenological analysis (IPA), which aims to understand in detail how individuals are "making sense of their personal and social world" (118). In this approach, the data collector tries to get an insider's perspective into the participant's experience by allowing them to share their experiences as witnesses and victims of collisions and to detail their proposed solutions in their own words.

5.2.3 *Study participants*

We used a priori maximum variation sampling to capture a wide range of perspectives. The critical dimension of variation that informed the sampling is road user type (VRU versus not). VRUs are defined as those who have less collision protection than those inside a motor vehicle, including pedestrians, cyclists, and occupants of powered two- and three-wheelers. Non-VRUs are defined as those who do have more collision protection such as drivers and passengers in private or commercial vehicles. Within each category, we made special efforts to include several types of vehicles to capture diverse cases. This strategy is intentionally different from convenience sampling in these locations, which would involve interviewing those that are easiest to access (114).

Road users were defined by a screening question ("What mode of transport do you use most often?", Prompts: walking, public transport including minibuses [i.e., trotro], bicycles, motorcycles, cars, taxis, trucks). The inclusion criteria for interviews were being 18 or older and consenting to an interview and audio recording. The completeness of the data drives qualitative study sample sizes, and small sample sizes (9-17 interviews) are often appropriate (119). For studies utilizing IPA, small numbers of participants are preferred, given the commitment to a detailed interpretative analysis of each case (118). We aimed to recruit 16-32 participants but allowed for some flexibility in sample size based on data saturation.

5.2.4 *Data collection and analysis*

We include the semi-structured interview guide in the *Appendix*. We developed it to address our research questions within the domains/phases of Haddon's Matrix, CFIR, and in alignment with IPA principles (i.e., encouraging the person to speak about the topic with limited prompting and leading). Two Ghanaian data collectors trained in qualitative methods conducted interviews. One data collector conducted the interview using a semi-structured guide, while the other recorded the interview and took notes. Although we proposed to recruit four to eight participants in each hot spots, we continued recruiting until we reached data saturation, defined as no new information or data (termed informational redundancy) (119). Interviews were conducted in Twi, Dagbani, or English, depending on the participant’s preference, and audio-recorded, followed by verbatim transcription/translation soon after the interview. Each transcript and translation were quality checked by the translator and by a second team member.

Analysis was conducted in Nvivo (120). We conducted content analysis, the approach used most in prior qualitative studies on collisions in LMICs (100, 121, 122). Applying Haddon's Matrix guided the initial coding procedure and relationships between variables and codes. After familiarization, we coded each instance of the predetermined categories and identified more specific codes (e.g., excessive speeding under human factors) inductively. Discrepancies between coders were discussed and resolved. For the IPA, we considered each case (participant) individually, and reviewed each transcript carefully to highlight important and interesting emergent themes. We have noted the transcript number of each quote in the results, and transcripts are available upon request.

5.2.5 *Positionality*

Neither of the Ghanaian interviewers was affiliated with the Ghanaian government or any entities related to road safety (e.g., the NRSA, the BRRI). Therefore, we do not suspect interviewer characteristics affected how participants' responses. The lead researcher and one of the interviewers were affiliated with the University of Washington and the National Institutes of Health Fogarty International Center, which funded this work. The other authors are affiliated with the University of Washington, the Kwame Nkrumah University of Science and Technology, the BRRI, and the NRSA, which may have affected their interpretation of participants' responses.

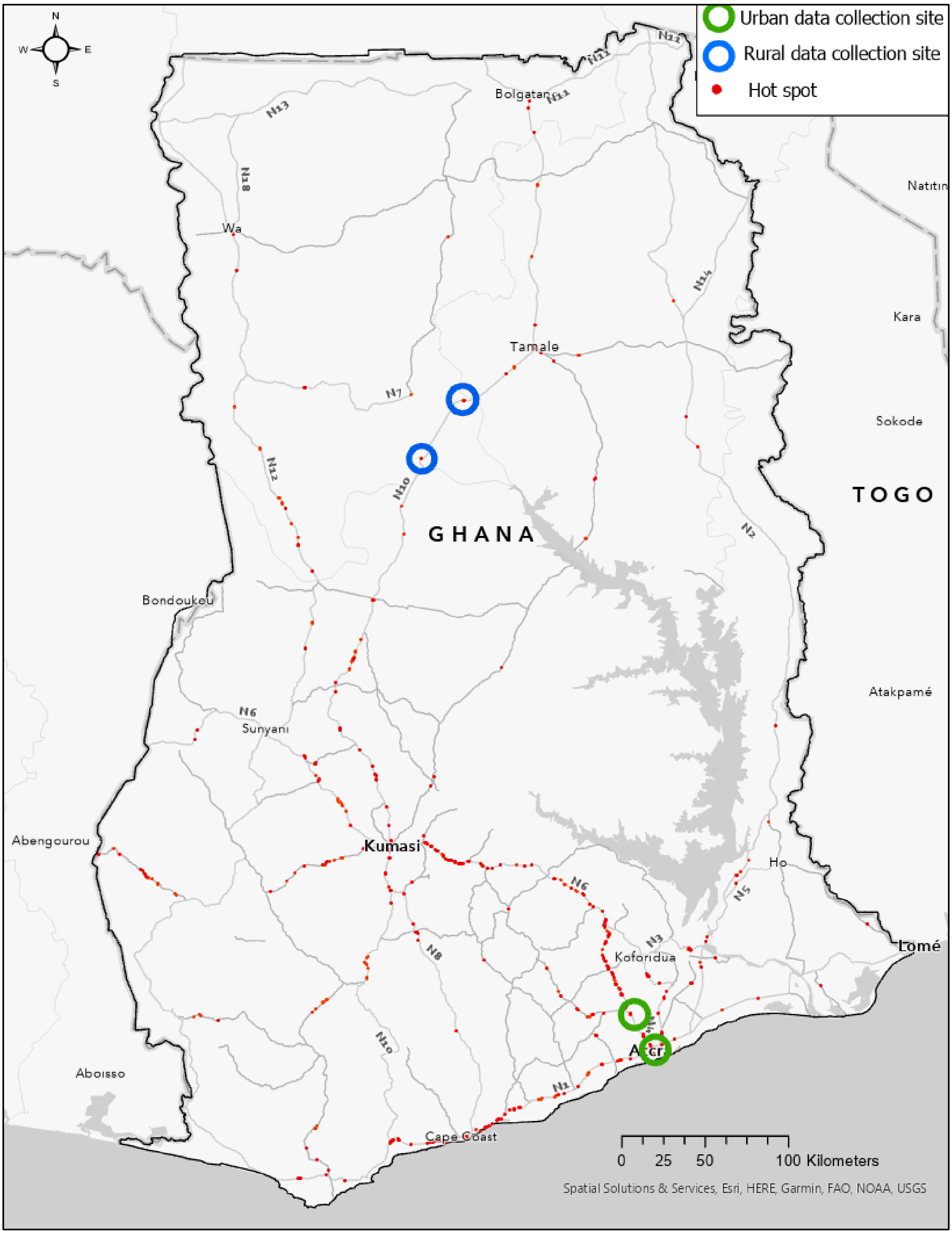
5.2.6 *Ethics*

This study received ethical approval from the Committee on Human Research, Publications, and Ethics at the Kwame Nkrumah University of Science and Technology (Study identification: CHRPE/AP/711/22) and the University of Washington Human Subjects Division (Study identification: STUDY00016536).

5.3 Overview of study and participants

We conducted 24 IDIs with road users in four hot spots: two urban hot spots in the Greater Accra Region and two rural hot spots in the Northern Region. The precise locations of data collection are shown in *Figure 5.2.* One urban location was at the Achimota junction intersection of National Road 1, a road spanning from the border of the Republic of Côte d'Ivoire to the border of Togo and National Road 6 from Accra to Kumasi. Both rural hot spots were located on National Road 10, beginning in Kumasi and ending at the Burkina Faso border. Both hot spots were south of Tamale, 54 km and 86 km from the city's center, respectively.

Figure 5.2 Data collection sites in hot spots of RTCs, injuries, and deaths[A]



A. Identified by national georeferenced data managed by the BRRI in Ghana

We present the characteristics of the 24 participants in *Table 5.1.* The mean participant age was 34 years. Most participants were male. We had 14 primarily VRUs (i.e., those who said they walked, cycled, or used a powered two- or three-wheeler to travel most often) and 10 non-VRUs (i.e., those who said they use a vehicle or bus to travel most often). Interviews lasted an average of 25 minutes (range: 13-60 minutes).

Table 5.1. Participant characteristics (N=24)

Characteristic	**Total, n (%)**
Location	
Urban hot spot	12 (50%)
Rural hot spot	12 (50%)
Age, mean (SD)	34.04 (9.4)
Sex	
Male	21 (87.5)
Female	3 (12.5)
Language	
English	6 (25%)
Twi	14 (58.3%)
Dagbani	4 (16.7%)
Primary vulnerable/non-vulnerable status	
Vulnerable	14 (58.3%)
Non-vulnerable	10 (41.7%)
Primary road user type	
Driver	17 (70.8%)
Passenger	3 (12.5%)
Pedestrian	4 (16.7%)
Primary vehicle type[A]	
Car	8 (33.3%)
Mini-bus	2 (8.3%)
Powered two-wheeler	7 (21.2%)
Powered three-wheeler	3 (12.5%)
No vehicle (i.e., pedestrian)	4 (16.7%)

A. These variables were developed from the response: "How you usually get around? How do you get to work?" to understand participants' primary means of transport

5.3.1 *The impact of road traffic injuries and deaths*

Most participants believed that collisions, injuries, and deaths were a major issue in the hot spot. All agreed on the magnitude of the problem nationally, like this respondent (*46-year-old-man, primarily car driver, rural, transcript 118)* who commented that “accidents are rampant.”-. Participants described how often they worried about the risk of collisions and how these experiences affected their behavior. They stated that road safety issues affected their daily actions with examples such as people avoiding certain areas due to the risk and substantial emotional toll, saying: "If you witnessed an accident here [in the hot spot], I tell you if you are not emotionally strong, you won’t want to come here again. You won’t be able to walk here.” *– 26-year-old man, primarily a motorcyclist, rural, transcript 115.* Other participants described the difficult experience of traveling or having loved ones travel using the terms “fear,” “panic,” “scary,” “horrible,” “terrible,” and “unbearable.”. Participants reported calling on religious beliefs, including for God to protect them or their relatives, to arrive safely at their destination.

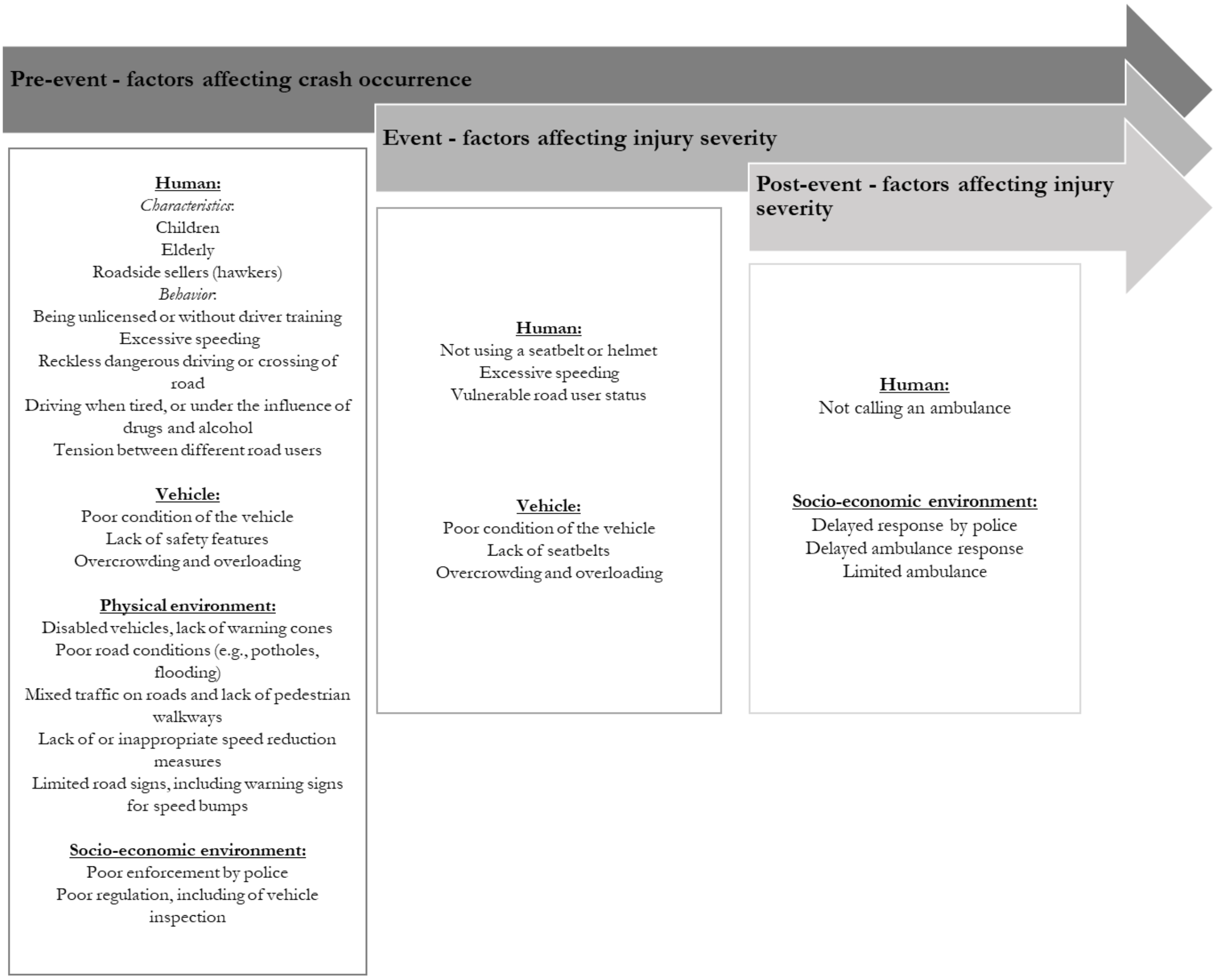
> "Today in Ghana, there is fear and panic, especially if a relative tells you that I am traveling. The entire family begins to put the destiny of that relative in the hands of God for fear of not returning to them. That is the extent to which accidents are affecting the country." *– 25-year-old woman, primarily pedestrian, urban, transcript 108.*

Nearly all participants reported distressing experiences of witnessing or being involved in a crash. The four participants involved in RTCs were passengers or drivers of vehicles, and two of them were injured. Over half of the participants reported witnessing a crash where a child was injured or killed, most often when crossing the road. When describing why road traffic injuries and deaths are such a concern for the nation, participants described stated that those deaths, particularly among children, negatively affecting national economic development, stating: "The child is a future somebody, but as he comes from school, a car will come and knock him down. Don't you see all these things send us back [in terms of development]?" – *25-year-old man, primarily a motorcyclist, rural, transcript 122.* Another participant saw this issue through the lens of missing out on improvements rather than negatively impacting development: "You don't know who will grow to become an important person and who is going to help Ghana in the future." – *26-year-old man, primarily a motorcyclist, rural, transcript 115.*

5.3.2 *Factors contributing to RTCs, injuries, and deaths*

Participants had many potential explanations for the large burden of RTCs, injuries, and deaths, which we have displayed within domains of Haddon’s Matrix in *Figure 5.3.* We briefly summarize a few important key factors below.

Figure 5.3. Contributing factors within the Haddon's Matrix according to IDI responses



On human-level factors, participants called out specific characteristics that put individuals at higher risk of being involved in a crash (e.g., being a roadside seller, termed hawker), and behaviors such as excessive speeding or crossing a road carelessly. Vehicle factors included the poor condition of vehicles, the lack of safety features, and overcrowded and overloaded vehicles. Physical environment factors included poor road conditions, mixed traffic, limited speed calming measures, and disabled and unattended vehicles on the roads or shoulders. Socioeconomic environmental factors included issues related to the police, including their limited, questionable, or low-quality enforcement, and delayed ambulance response times after a RTC. Two interesting physical environment findings were that disabled and unattended vehicles and a lack of signs or warning before a speed bump(s) could cause collisions or injuries. Most participants stated these features (disabled cars and speed bumps) could be challenging to see, particularly at night in the setting of limited street light infrastructure, which could lead to adverse outcomes. In addition, they stated that disabled vehicles are often on the road for days or weeks and that the lack of warning signs means that cars may approach the speed bumps at high speed, which may result in a crash or vehicle damage.

Although rarely stated as a definitive cause of collisions, injuries, and deaths, one notable emerging theme among participants was that many factors were related to socioeconomic conditions. First, participants described low economic status underpinning the increased risk of adverse outcomes for specific people. For example, hawkers must sell goods near cars and on the sidewalks: "someone selling on the pavement, it's not right for people to do that because it was meant for people to pass, but because of the system and economic hardship, people are here to trade.” – *46-year-old man, primarily a mini-bus passenger, urban, transcript 102* and motorcycle taxis (termed okadas): “I will make the okada riders to stop work for I have seen that its due to economic hardship that is making them do that.”— *21-year-old man, primarily commercial driver, urban, transcript 110*. Second, participants stated that many of the observed vehicle issues, including tire, brake, and safety features, arise because drivers cannot afford to repair or replace the vehicles: "It [the car] does not deserve to be on the road at all. But because of economic hardship, he's still working with it." – *46-year-old man, primarily a mini-bus passenger, urban, transcript 102*. Private and commercial drivers were included in this finding: "Some buses carrying passengers [...] will say ‘let me go and manage if I get money, I will change the tire."' – *26-year-old man, primarily a motorcyclist, rural, transcript 115*.

5.3.3 *Current road safety successes and gaps*

Most participants were aware of some existing road safety measures, including speed bumps, pedestrian footbridges, and educational campaigns. When prompted with questions on the government's road safety efforts, opinions differed dramatically. Most participants acknowledged the existing efforts but stated that the government must address the burden of collisions, injuries, and death, as noted by a 39-year-old man (*primarily a powered three-wheeler driver, rural, transcript 116)* stating, “we are pleading to the government to do more. What they are doing is not enough.” When asked about the government, participants often referred to elected officials, with a 48-year-old man (*transcript 109*) stating that they only “care […] about their pocket and their position.” Some believed that policymakers do not keep promises they make during the election process, stating: “They will just say it, but when they get the power, they don’t do it.” *– 46-year-old man, primarily a mini-bus passenger, urban. transcript 102*. Participants described officials spending substantial time discussing the issues rather than acting on the problems. Of note, participants spoke broadly about the government or elected officials, rather than calling out specific agencies responsible for road safety.

Despite negative comments, participants described some successes that included improved road conditions, including repaired potholes, new or resurfaced roads, reflective paint, and newly constructed pedestrian footbridges. Regarding footbridges, a 46-year-man described the positive impact in the hotspot: “before the footbridge car use to knock people every day, in and day out. But after the construction of the footbridge, now it has reduced.” – *primarily mini-bus passenger, urban, transcript 102.* Other successes included the enforcement by police, with one participant reporting that, “the police do their best to protect us.” *– 35-year-old man, primarily powered three-wheeler driver, urban, transcript 107*, and the proliferation of ambulances: “We just got a new ambulance, […] anytime we call them they come fast.”*– 28-year-old man, primarily motorcyclist, rural, transcript 121.*

On ambulances, the participants described the equitable response of ambulances. When prompted on any disparities in access (e.g., urban versus rural, ability to pay), participants stated that ambulances would arrive regardless of any such factors: “No, they don’t look at any person, […] whom you are, where you are coming from. They do help if it is anyone at all.” *– 26-year-old man, primarily motorcyclist, transcript 124*. However, other participants stated that, ambulances take a long time to arrive (“The last time they [bystanders] called an ambulance, [the ambulance said] it would be about an hour.” -– 32-year-old man, primarily a car driver, rural, transcript 123). Additionally, it was reported that individuals most often do not call ambulances after a collision and instead rely on community members and Good Samaritans to bring the injured to the hospital.

Participants described current implementation gaps of existing interventions. Gaps included a lack of specific interventions such as the quantity or timing of enforcement: “During the day, they enforce the law very well […]. But in the night, where they are gone is where most of the accidents occur.” *– 48-year-old man, primarily a car driver, urban, transcript 109*. Beyond gaps in the interventions, they also acknowledged limitations of existing interventions, for example, speed bumps being poorly constructed (“Some of the speed bumps don’t last. They don’t include enough […] cement.” *– 41-year-old man, primarily a car driver, rural, transcript 120*), and road users not utilizing existing infrastructure designed to increase safety, as one participant (*46-year-old man, primarily a mini-bus passenger, urban, transcript 102*) highlights by concluding “due to our stubbornness and laziness, we don’t use the footbridge. We prefer to cross the road instead.” Views on enforcement were mixed, but some participants highlighted police corruption, including that road users violating laws can pay a bribe “instead of the police arresting the driver, they will take a token from them and allow them scot-free*" – a 46-year-old man, primarily a mini-bus rider, urban, transcript 102*, which may undermine road safety improvement efforts in the country.

5.3.4 *Engagement in road safety*

Most participants stated they did not have any experience indicating their voices or views are considered in road safety decision-making. One 28-year-old man (*primarily motorcyclist, rural", transcript 121)* stating *"*the government doesn't come and ask about the thing we want," leading to reports of feelings of neglect among other participants: "They don't respect our lives." *– 35-year-old man, primarily a motorcyclist, rural transcript 122.* Some participants described taking road safety matters into their own hands. For example, one participant (*41-year-old man, primarily car driver, transcript 120)* reported, "[in] this place, accidents were […] too much, we decided to make our own speed rump," as the government was not responding to their requests promptly.

In contrast, a few participants described positive engagement leading to feelings of empowerment. For example, a 34-year-old man (*primarily motorcyclist, rural, transcript 122*) eagerly noted, "When people complained to the district assembly, they came and did the speed ramp for us." Another respondent was pleased to be interviewed by a news station after a severe crash occurred:

> "There was an accident here. […] which caused a very long traffic [so] that people were not able to go to work. Some reporters from […] the television station came around to interview us, and I really poured my heart out to them. I explained to them the reasons for frequent accidents in the area, and as you can see now, the road is being expanded to help reduce accidents. This actually proves to me that the government really

listens to us." – *30-year-old woman, primarily pedestrian, urban, transcript 112.*

5.3.5 *Proposed road safety solutions*

We offered participants an opportunity to describe what they believed could reduce collisions, injuries, and deaths. *Table 5.2* presents the proposed solutions and the related reported contributing factor within Haddon's Framework.

Table 5.2 Contributing factors and corresponding proposed solution

Haddon's Matrix Level	**Proposed solution**	**Illustrative quotes**
Human	Contributing factor: Drivers driving under the influence of drugs, alcohol, or when tired	
	Drivers, and particularly commercial drivers, need to reduce drinking, drug, driving while tired	"What I think will decrease the risk of accidents here [is that] the buses, they should give them two drivers […]. [With] one driver, when he is tired, it can cause an accident […]. When there are two drivers, if one feels like sleeping, then one will also take over." – *41-year-old man, primarily car driver, rural, transcript 120.*
	Contributing factor: Road users not obeying or knowing the road safety laws	
	Education for road users, including pedestrians, children, and the general public Training for drivers on how to safely drive	"Training -- the government has to bring it onboard for them [drivers] to learn before they get on the road." *46-year-old man, primarily a mini-bus passenger, urban, transcript 102.* "I will add road safety laws to our educational curriculum so that it will enlighten their [children's] knowledge." – *35-year-old man, primarily a powered three-wheeler driver, urban, transcript 107.* "Educate the general public on road safety." – *56-year-old man, primarily car driver, urban, transcript 105.*
	Contributing factor: drivers drive carelessly, recklessly, and speed excessively	
	Drivers should reduce careless, reckless driving, and pedestrians need to reduce dangerous crossing of the road	"I will advise pedestrians to be careful when walking on the roadside." – *22-year-old man, primarily a mini-bus passenger, urban, transcript 101.* "Drivers have to be careful, over-speeding and wrong overtaking." – *35-year-old man, primarily a car driver, rural, transcript 119.*

	Drivers should reduce excessive speeding, particularly when entering communities and busy areas	"If you [the driver] get there, slow down; people live there; some sell by the roadside." – *30-year-old woman, primarily a pedestrian, urban¸ transcript 112.*
	Contributing factor: Limited helmet and seatbelt use	
	Drivers, passengers, and motorcyclists are urged to always wear helmets and seatbelts	"The accident's impact can be reduced when you are wearing a helmet."– *28-year-old man, primarily a motorcyclist, rural, transcript 121.* "We will plead with drivers to wear their seatbelt." – *30-year-old woman, primarily pedestrian, urban, transcript 112.*
Vehicle	Contributing factor: vehicles are not fitted with seatbelts, enough seats, or safety features	
	Seatbelts should be mandated, installed in vehicles	"Every vehicle is supposed to have seat belts and enough space." – *28-year-old man, primarily a motorcyclist, rural, transcript 121.* "For cars, if you are onboarding, your safety should be guaranteed. If there is an accident, since all those things that protect the passengers are not available, the accident will be fatal."– *26-year-old man, primarily a car driver, urban, transcript 106.*
	Cars, buses, and powered three-wheelers should not be overloaded with passengers or goods	"When they [vehicle owners] are fixing the seat, they should position the seat with intervals." – *30-year-old woman, primarily a pedestrian, urban, transcript 112.*
	Contributing factor: poor condition of vehicles	
	Vehicles should be inspected for roadworthiness or removed from roads	"Some of the vehicles […] need to be seized." – *28-year-old man, primarily a motorcyclist, urban, transcript 111.*
Physical environment	Contributing factors: poor road conditions, limited signs, including warning signs for speed limits	
	Improved roads, reduced curves, improved signs, including speed bumps	"If they were to be a listening government, Kumasi to Accra Road should […] be made dual." – *48-year-old man, primarily a car driver, urban, transcript 109.* "They should reconstruct the gutter here so that any time it rains, there will be no flood."– *21-year-old man, primarily a commercial driver, urban, transcript 110.* "Put up road signs to guide new or foreign drivers to their destination." – *30-year-old woman, primarily pedestrian, urban, transcript 112.* "They should construct the speed bump with reflected stripes to alert the drivers from a distance. – *35-year-old man, primarily a car driver, rural, transcript 119.*

	Contributing factor: numerous disabled vehicles on or alongside the road, limited warning triangles to tell drivers about the upcoming disabled vehicles	
	Reduced disabled vehicles on the road, put warning signs before disabled vehicles, and remove warning signs after the vehicle is removed	"The people around should help push the car to the proper place, or the police should get a towing car to tow the car off the road, […] 24/7 every day." – *26-year-old man, primarily a car driver, urban, transcript 106/*
	Contributing factors: mixed traffic on roads and lack of pedestrian walkways	
	Separate road users (including for trade), build infrastructure such as sidewalks and footbridges	"I will construct separate roads for bicycles, motorbikes, and cars." – *22-year-old man, primarily a mini-bus passenger, urban, transcript 101.* "I would move all the hawkers by the roadside to a very safe place allocated to them." – *35-year-old man, primarily tri-cycle driver, urban, transcript 107.*
	Contributing factor: Limited speed calming measures	
	Install speed measures, including speed bumps, speed cameras, and speed governors (in-vehicle speed monitoring)	"More speed bumps should be constructed." – *22-year-old man, primarily a mini-bus passenger, urban, transcript 101.* "I will put a machine inside the car to limit their speed; if you speed beyond that limit, it will not go. I will also fix cameras in town to check [the drivers'] speed limit." -- *56-year-old-man, primarily a car driver, urban, transcript 105.*
Socioeconomic environment	Contributing factor: limited ambulances and delayed ambulance response	
	Education on first aid and on the transport of injured	"People selling don't have any knowledge about first aid, so the government should select people to come and educate them." – *46-year-old man, primarily a mini-bus passenger, urban, transcript 102.*
	Increased or strategically allocated ambulance and health centers	"I will increase the number of ambulances." – *28-year-old man, primarily a motorcyclist, rural, transcript 121.* "Since this place is busy, if we get an ambulance as a standby, it will help." – *56-year-old man, primarily a car driver, urban, transcript 105.*
	Contributing factor: poor or limited enforcement	
	Increased enforcement, includin with military officials	"Where there is a footbridge, […] I will employ the service of the military men and policemen […] to enforce the road safety laws."– *35-year-old man, primarily a powered three-wheeler driver, urban, transcript 107.*

5.4 Discussion

The gravity of road safety issues in Ghana and other LMICs is substantial, with participants in this study demonstrating a thorough understanding of the problem's magnitude. Participants described their frequent and distressing experiences of crashes and how these experiences affected their behavior. Policymakers, however, have yet to fully grasp its significance. In 2020/2021, NRSA received a notable increase in funding ($5.06 million to 3.76 million in 2018/2019) (123). This increase, fostered by the NRSA Act 2019, signifies progress, but is insufficient in addressing this public health crisis, particularly when considering the economic toll inflicted by road-related severe injuries and fatalities ($4,507 million estimated losses, 8.2% of GDP in 2016) (16). The urgency of this public health crisis and the economic imperative for investment in Ghana and other LMICs are paramount. Despite the 1.3 million deaths, 50 million injuries, and macroeconomic loss estimated at $1.8 trillion from 2015-2030, this issue is often sidelined to other health conditions. The escalating trends of urbanization and motorization forecast a worsening scenario without urgent action. Therefore, we implore leaders in Ghana and other LMICs to acknowledge this crisis and allocate resources accordingly. To put it simply: "we are pleading for the government to do more."

In line with this plea, we highlight participant perceptions on the contributing factors, gaps, and potential solutions. Respondents noted several key contributors to crash frequency and severity, complementing existing literature (5). Participants ubiquitously reported human-level contributing factors, implementation gaps, and proposed solutions. They frequently discussed road user behavior and the need for increased police enforcement. This narrow view of solutions may reflect road users' familiarity with existing policies, which emphasize prosecuting drivers and public education (124). Previous studies corroborate these themes, highlighting road users' personal responsibility for their own safety (104) and attributing injuries and deaths to risky road user behavior like drug use and speeding (101, 102, 108, 109, 110). These findings also align with the global focus on changing road user behavior among policymakers and practitioners (125). While road users undoubtedly share a collective responsibility for safety, adapting a road network that accommodates human vulnerability is essential, as per the leading Safe Systems Approach (30, 31). Road users should not be blamed if the system fails to address these vulnerabilities. Further, behavior change strategies can face implementation challenges and may have limited effectiveness. (125). A recent review of road traffic injury prevention in LMICs observed mixed results for road user-focused efforts, including public awareness and educational campaigns (96, 126). Increased police presence led to a reduction in deaths in Kampala (127), while drunk-driving enforcement in Mexico led to fewer crashes but did not affect injuries or fatalities (128). Participants often described the need for speed management interventions, such as automated speed enforcement cameras and speed governors, which have been implemented nationally in Rwanda (129, 130), and are currently being piloted in Ghana, indicating a program and populations need alignment.

Participants identified the poor condition of vehicles as a key factor and potential solution, aligning with research linking non-genuine car parts, substandard mechanic work, and inadequate repair supervision to RTCs in Ghana (131), and prior road user perception studies on the causes of collisions (107, 109). The absence of safety features was stated to increase the likelihood of occupant injury or death. Given that Ghana does not meet some UN Vehicle Safety Regulations, the lack of safety feature finding is unsurprising (16). Within the physical environment category, respondents highlighted unique Ghanaian factors such as the prevalence of disabled vehicles on roads and inadequate warning signs before speed calming measures. These issues mirror those raised by Ghanaian road safety experts in a recent modified Delphi study (84).

Proposed solutions included many which are well-aligned with evidence-based practices from around the world, such as traffic calming measures (132, 133), improved road designs (125, 134), warning signs about hazards (63), roadside and central barrier systems (135, 136), and the separation of road users such as pedestrians (137, 138, 139), cyclists (140, 141, 142), and motorcycle occupants (143, 144). The socioeconomic environment category primarily addressed prehospital care, a key element in minimizing crash-related harm (145). Annually, an estimated 54% of the 45 million deaths in LMICs could be managed with prehospital and emergency care, with unintentional injuries, including those from collisions, contributing the most to the preventable morbidity burden (146). Participants suggested community first aid, previously successfully introduced to commercial drivers in Ghana (147), and strategic allocation of ambulance services. However, they universally reported relying on community members and Good Samaritans for transport to the hospital, a common scenario in LMICs (146, 148, 149), indicating potential demand-side barriers to prehospital care despite supply-focused solutions.

One notable takeaway across Haddon's Framework was the participants' focus on implementation. They identified existing gaps in interventions and proposed solutions. These gaps included limited enforcement, a need for road users to adhere to safety laws independently of enforcement, and poor-quality infrastructure interventions. For instance, participants suggested government-constructed speed bumps with reflective stripes and additional overhead footbridges with enforcement to ensure utilization. Such recommendations speak to the need for designing, adapting, and testing interventions and implementation strategies in Ghana and LMICs (150, 151). Issues related to the intervention characteristics and implementation strategies can negatively affect acceptability, adoption, cost, penetration, and impact (150, 152, 153). Although there are positive impacts of separating road users with footbridges (125), this effect may not be observed if the footbridge is implemented poorly, leading to limited acceptance and utilization (106, 153, 154). Therefore, we recommend that road safety agencies consider and document local adaptations to interventions (155). This includes modifying the intervention itself, its delivery, evaluation, and the strategies used for implementation or spread (156) to improve the reach, effectiveness, sustainability and alignment with local needs (157).

Our participants, like other Ghanaian community members, express feelings of discontent with the lack of interventions. This discontent has led to them constructing unauthorized speed-calming measures (158, 159, 160), reflecting a politicized issue evidenced by "no speed bumps, no votes" billboards during elections (161). This indicates policy implementation efforts are not meeting Ghanaians' needs promptly, a phenomenon also seen in Africa and Latin America (126, 162). Existing measures, especially speed-related, are questioned for their effectiveness and suitability. Despite studies showing speed bumps reduce injuries and deaths (112, 132, 161), excessive speeding remains common (163) due to ad hoc implementation based on varying factors, rather than standardized guidelines (112, 164). Consequently, reports of poor road safety measures and their negative effects have led to speed bump relocation or removal on major roads (113, 160) and calls for speed calming measures to be restricted to residential streets, rather than high-speed arterial roads (112, 165). Despite the richness of their insights, road users felt unheard, indicating a need for their greater participation in road safety dialogue. Out of the limited qualitative studies on African road users, only three involved Ghanaians (101, 102, 103), underscoring the importance of acknowledging this neglected population's experiences and input. While road safety initiatives are typically government-led (i.e., by the NRSA in Ghana), community involvement could enhance support and improve outcomes. Current efforts to inform the public about road safety, which include workshops, seminars, radio and TV discussions, and the operation of a road safety call center, could be extended to involve community members in problem identification and solution finding, following the WHO Safe Communities program recommendations (166, 167). This approach, particularly when targeting high-risk groups and evaluating program impacts, can promote effective interventions and foster public trust.

Our study is subject to some limitations. Despite using maximum variation sampling and achieving data saturation, the small sample size may limit the diversity of perspectives. Also, using a semi-structured questionnaire based on Haddon's Matrix could have influenced participants' responses and potentially discouraged policy- or system-level suggestions. There was also potential social desirability bias, especially concerning government or police actions, although measures were taken to minimize this (i.e., reassurance that lead researchers and data collectors were not affiliated with government entities) (114, 168, 169). Despite these factors, we believe our study, which centers road user voices to contribute to Ghana's road safety dialogue, provides trustworthy findings (114, 168, 169).

5.5 Conclusion

Guided by this qualitative study, our key recommendations are for the governments of Ghana and other LMICs' to recognize and address the pressing public health crisis of road traffic injuries and deaths. We encourage road safety agencies and practitioners to not only implement evidence-based interventions but also to ensure their relevance through local adaptations. Lastly, we urge road safety agencies to engage with communities for locally tailored solutions.

Chapter 6. Conclusion

We presented four studies that aimed to develop contextually relevant evidence on high-risk areas and factors for targeted road traffic injury prevention initiatives in Ghana. Our work was in line with Safe Systems Approach in road safety, which focus on proactively identifying and reducing severe road traffic injuries and deaths. In Chapters 2 and 3, we were able to identify spatially specific and detailed information on the high-risk areas in space and time. In these two studies, we had several innovative and contextually relevant components. First, we greatly improved the usefulness of the MVC database for future spatiotemporal analyses by establishing a geocoding methodology. Second, we are using rigorous geospatial methods (the Getis-Ord Gi* hot spot analysis and emerging hot spot analysis in ArcGIS Pro) to identify hot spots. These approaches go beyond mapping raw data, which has been deemed insufficient in identifying spatial clusters of crashes (170). Third, rather than simply reporting counts, we employed a weighting system which assigns greater weights based on severity to identify unsafe locations. Fourth, we have determined analysis specifications to meet the needs of the context and implementation/research collaborators in Ghana, including conducting a national analysis stratified for urban and rural areas.

In Chapter 4, we responded to road safety experts' calls to better understand VRU risks in Ghana (84). We conducted a retrospective study on factors associated with injury severity for VRUs, non-VRUs and VRU subgroups with five years of data (2016 to 2020). We found factors which are consistently increasing the odds of severe outcomes (e.g., head-on collisions, collisions at night with no lights or the lights off, and collisions in rural areas or villages). Beyond these, most predictors were specific to only one or two road user types, indicating that a targeted and road user specific approach for injury prevention is warranted. Innovative features of this work included the focus on comparing and contrasting factors based on vulnerability status. We also acknowledged the differences in VRU subgroups and assessed each individually. We also used an innovative statistical analysis approach (a partial proportional odds model), which considers the differential impacts of a predictor on different levels of an ordinal outcome.

In our final Chapter, we centered road users' voices and explored their perspectives on the magnitude of, contributing factors, and potential solutions for road traffic injuries and collisions. We found that participants had a complex understanding of the magnitude of the problem and of implementation issues which may limit the effectiveness of existing road safety measures. We show the complexity and insightfulness of their perspectives, and the importance of their participation. We believe there is an evident need for greater involvement of the community to adapt interventions to meet their needs, and for the government to acknowledge and act on this alarming public health issue.

Next steps for our work include dissemination with in-country collaborators and stakeholders, and evaluation studies to expand the evidence base in Ghana and LMICs. First, we are conducting a stakeholder dissemination event to present our findings from the portfolio of research to the NRSA, GHA, the police, the national ambulance service, and other key road safety partners. We will lead discussions on solutions which could be implemented quickly or relatively simply (e.g., the low-hanging fruit) as well as interventions which may take more time, research, or resources to implement. Closely related to this effort, we are conducting training on geospatial and statistical methods to ensure the sustainability of this work in Ghana.

Second, to build on this work, our team will pursue additional studies that are informed by the population and contextual needs. We will conduct two hybrid implementation-effectiveness studies. The first, which addresses key significant factors from Chapter 4 (head-on collisions, medians) will be to assess the impact of dualization of major roads on RTCs, injuries, and deaths in Ghana using a retrospective controlled quasi-experimental design. We will use our mapped outcomes of RTCs, injuries, and deaths on roads to determine if the built environment intervention changed road safety patterns. This work will inform future infrastructural interventions on major roads. The second study builds on the findings related to footbridges in Chapter 5. Participants noted some key issues with footbridges, including the lack of enforcement, and limited utilization. To develop a deeper understanding of this issue, we will conduct a study on several footbridges. We collect quantitative information on utilization and qualitative information on the features which may be related to implementation. The intention of this work is to inform future implementations of footbridge interventions, ones which will include considerations for adaptations to the local context and population needs.

Broadly, we believe that this work makes an important contribution to the literature and shows what is possible when high-quality and spatially specific data is collected, maintained, and utilized for rigorous evaluation. Such data enables a detailed understanding of risk in terms of space, time, and road users, which is critical for targeted and effective implementation of road traffic injury prevention. We have provided sufficient detail about our data processing, methods, and key decisions to facilitate future studies in other LMICs grappling with a similarly high burden of injuries and deaths. Our hope is that this can serve as a framework for other countries which may be setting up or maintaining similar systems and planning targeted resource-efficient interventions. We see the potential of such data and implementation of science approaches for informed decision-making to spur progress in injury prevention. Beyond this, we see greater potential for existing (e.g., satellite imagery) and future data and similar approaches as a means of reducing global inequities.

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Chapter 7. Appendices

CHAPTER 1 APPENDIX

Literature review for complete dissertation

Introduction: In this section, we conducted a literature scoping review to systematically map the literature on geospatial, statistical, and qualitative approaches to understand road traffic crashes (RTCs), road traffic injuries (RTIs), and road traffic fatalities (RTFs) in Africa. We conducted this review in July 2022 accordance with the Arksey and O'Malley Framework, a widely used methodological framework for scoping studies and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) checklist (171, 172). A scoping review is suitable as we sought to summarize the evidence on geospatial, statistical, and qualitative methods utilized for road safety in Africa, rather than answer a narrowly defined research question and assessment of the quality of included studies (which would be done in a systematic review) (173). In the following sections, we describe the four main steps of a scoping literature review.

Methods: *Research question identification***:** Three questions guided this work, listed below.

1. What is known about geospatial methods in understanding RTC, RTIs, and RTFs in Africa?
2. What is known about context-specific and multi-level factors that influence crash severity in Africa?
3. What is known about community (i.e., road user) perspectives on RTC, RTIs, and RTFs in Africa?

Given the distinct foci of the research questions, we conducted three separate literature searches for each question, described below.

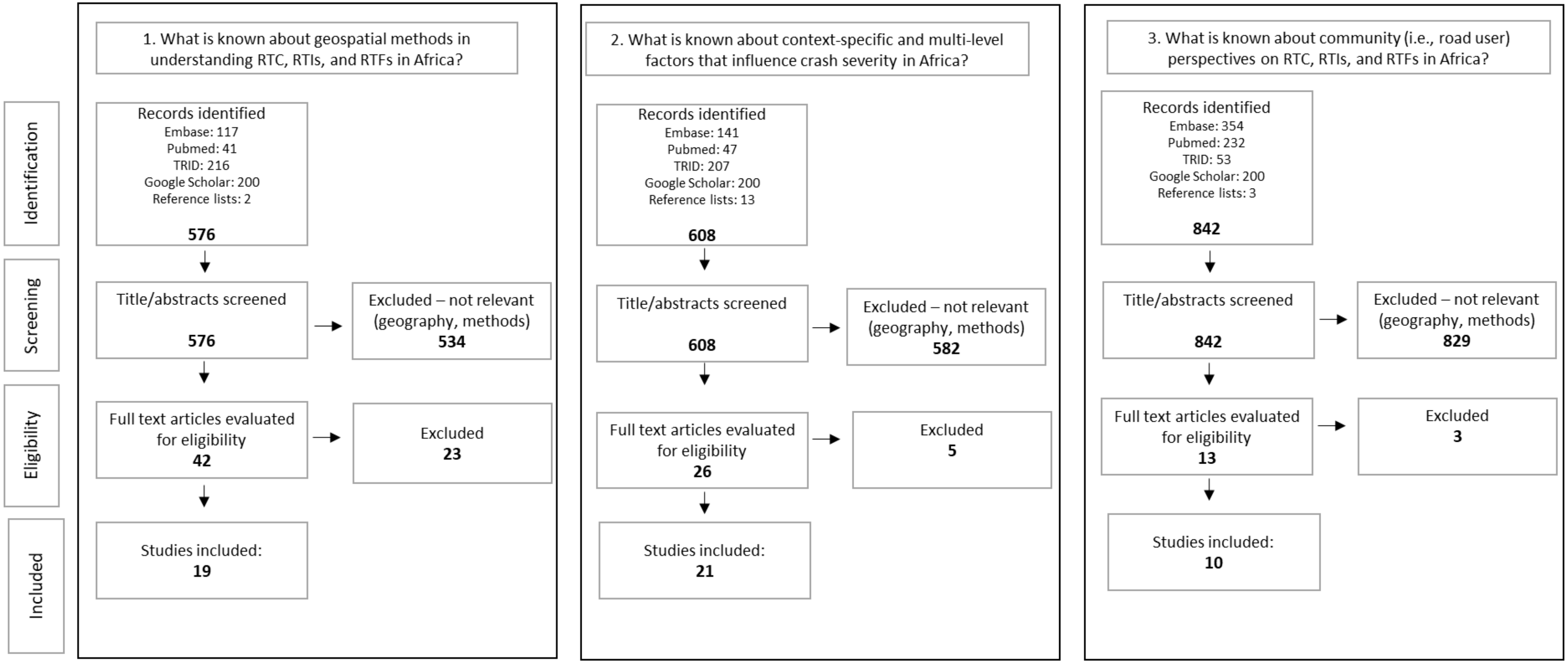
Literature Search: We conducted a systematic search of all relevant peer-reviewed publications from June 6-11, 2022. We used four academic databases in this review: EMBASE, PubMed/Medline, Google Scholar, and Transport Research International Documentation (TRID). We chose these databases as they cover a broad range of public health, social science, and transportation journals, allowing us to find all relevant indexed peer-reviewed publications. Search terms varied for each of the research questions and are described below in *Table 1.*

Table 1: Search terms

Research Question	Topic	Method	Population
What is known about geospatial methods in understanding RTC, RTIs, and RTFs in Africa?	Crash, collision, accident, motor vehicle, road traffic, road traffic injury, road traffic death, road traffic morbidity, road traffic mortality	Hot spot, black spot, spatiotemporal, spatial, geospatial, geographic information systems, GIS	
What is known about context-specific and multi-level factors that influence crash severity in Africa?	Crash, collision, accident, motor vehicle, road traffic, road traffic injury, road traffic death, road traffic morbidity, road traffic mortality	Injury severity	
What is known about community (i.e., road user) perspectives on RTC, RTIs, and RTFs in Africa?	Crash, collision, accident, motor vehicle, road traffic, road traffic injury, road traffic death, road traffic morbidity, road traffic mortality	Qualitative, interviews, focus group discussions, perspectives, observations	Road user, pedestrian, cyclist, motorist, passenger, driver

Study selection: We screened all titles/abstracts for inclusion and exclusion criteria to ensure that selected articles are relevant to each research question. The inclusion criterium were peer-reviewed articles; published in English; with full-text accessibility via University of Washington (UW) library service; published in 2000 and later (to capture recent and updated literature); and analyzing/reporting primary or secondary data. Exclusion criteria included any articles that were not written in English, taking place outside of Africa, not reporting primary or secondary data (e.g., systematic reviews, commentaries, meta-analyses, literature reviews, scoping review, modelling studies,) and published before the year 2000. As is recommended by the PRISMA guidelines, we present study selection results in *Figure 1*.

Figure 1: Study selection procedure flowchart



Data extraction: Once articles were screened and selected, we conducted data extraction. We extracted variables including information on the article (title, authors, journal, year, country), methods (data source, data collection period, analysis), and key findings for each research question.

Results: We identified a total of 50 studies for the literature review (Question 1:19; Question 2: 21; Question 3: 10) A total of 1,936 were deemed not relevant, often because of the geographic focus or because they lacked the methods (spatial, severity analysis, or qualitative). After title/abstracting screening, we deemed 81 eligible for full-text review. During full-text review, we excluded another 31. In the following sections, we will present detailed information and findings from studies relevant to each research questions.

Section 1: What is known about geospatial methods in understanding RTC, RTIs, and RTFs in Africa?

A total of 19 geospatial studies assessing RTCs, RTIs, and RTFs in Africa have been conducted since 2000. Detailed findings are presented in *Table 2.* Most of the studies took place in Nigeria (n=7) (41, 45, 46, 47, 49, 50, 51), followed by Ethiopia (n=4) (44, 48, 174, 175). Most studies utilized data from police or administrative departments (41, 43, 44, 45, 46, 47, 48, 50, 55, 83, 174, 175, 176, 177, 178, 179). Outcomes included RTC, RTI, and RTF incidence rates, counts, injury severity with most studies reporting more than one outcome. The most common type of analysis was Moran's I (n=6) (46, 47, 50, 51, 174, 180) and Getis-Ord Gi* (n=6) (48, 50, 51, 55, 174, 175). Several studies (n=5) did not use geospatial statistical analyses but rather reporting the number/frequency of RTCs/RTIs/RTFs in specific geographies (41, 42, 43, 44, 45). The majority (63%) aggregated outcomes to a geographic area, such as the state level (n=3) (41, 46, 47), regional level (n=1) (48), and local government area (LGA) level (n=4) (43, 49, 50, 51). Overall, all studies besides one reported areas of high RTC/RTI/RTF burden for the geographic area of study (47). Some hot spots were highly specific – such as Patel, Krebs *et al.* which identified exact locations in Kigali, Rwanda through Kernel Density Estimation (KDE) (176) whereas others reported states with higher counts of adverse road safety outcomes (46, 47).

Table 2: Summary of road traffic geospatial studies in Africa (2000-2022) (n=19)

Author, year	Setting	Data Source; years	Outcome; N	Type of Analysis; level of geographic analysis[A]	Areas of hot spots[B]
AkliluToma, Senbeta et al. 2021 (174)	Hawassa City, Ethiopia	Hawassa City Administrative Police Department; October 2013-June 2018	Annualized incidence rate (RTC per 1,000 people); 417 RTCs	Moran's I and Getis-Ord Gi*, administrative level analysis of Kebeles (smallest administrative area in Ethiopia)	• Gravel road RTC: Tulla town, Tulla Geter, and Chefe Cine Kebeles • Sunny weather RTC: Millennium Adebabay, Dume, Hiteta, FaraBariso and Chefa Kote Jabessa Kebeles
Ouni and Belloumi 2019 (180)	Highways in North-West, Center-East, and Center-West Regions in Tunisia	National Observatory for Information, Training, Documentation and Studies on Road Safety collision database; 2002-2013	RTCs in basic spatial units, total victims (RTIs and RTFs) in basic spatial units; 13, 242 RTCs, 23,086 RTIs, 4,200 RTFs	Moran's I and Getis-Ord Gi* for three time periods (2002-2005; 2006-2009; 2010-2013) for basic spatial units (1 km long fixed segments on roads)	• RTC: Highways in rural areas Northwest and Center-West regions • RTC: National highway 1 and national highway 2 near urban activities in the Center-East region
Patel, Krebs et al. 2016 (176)	Kigali, Rwanda	Kigali Traffic Police data; 2013	Density of events within 1000 meters and by RTC severity: 2,589 RTCs	Kernel Density Estimation	• RTC: Densely populated areas (downtown Kigali, the northern region of Nyrungenge with the boundaries of Gssabo and the southern part of Gasabo close to Kicukiro)
Tola, Demissie et al. 2021 (48)	Ethiopia, and a focus on the Oromia region	Police commission crash data; 2014-2017	RTC rates; RTC severity index	Getis Ord Gi*, regional level	• RTC: On a national-level, Oromia region and Addis Ababa • RTC: Within Oromia, East Shewa and Burayu town
Audu, Iyiola et al. 2021 (49)	Ibadan North-East local government area of Oyo State, Nigeria	Not reported; not reported	RTCs; not reported	Network and kernel density estimation analysis, LGA level analysis	• RTC: The north-eastern and south-western parts of Ibadan North-East The Old Ife – Onipepeye route
Yahaya, Yusuf et al. (45)	Kaduna metropolis, Nigeria	Federal Road Safety Corps; 2016	RTIs, RTFs; not reported	Descriptive, land marks and roads within the city	• RTF: UTC Bus-stop in the township and at Rigacikum on the Kaduna-Zaria Express Way (n=3) • RTI: Rigacikum
Shaw, Wangara et al. 2017 (177)	Nairobi county, Kenya	Ma3route app; 5/2015-5/2015	RTCs; 986 RTCs	Not reported	• RTC s: Thika Road; Waiyakwe Road; Mombasa Road
Akinyemi 2019 (46)	Nigeria	Federal Road Safety Corps; 2007-2009	RTC, RTI, RTF counts; not reported	Global and Anselin's Local Moran's I; Geographically weighted regression, analyses conducted on a state level	• RTF: Kano, Kaduna, FCT, and Nassarawa States • RTI: Niger, Kaduna, FCT, Kogi, and Nassarawa States
Daniel, Adejumo et al. 2017 (47)	Nigeria	Federal Road Safety Commission; 2007-2015	Average RTC rate per 100,000; RTF per 100,000; 83,548 RTCs, 76,822 RTFs	Global and Anselin's Local Moran's I; Geographically weighted regression; state level analysis	• Not reported

Korter, Olubusoye et al. 2013 (50)	Oyo State, Nigeria	Federal Road Safety Commission; 2011- 2012	RTC counts; not reported	Moran's I and Getis-Ord Gi*, LGA-level analysis	• RTC: Oyo West, Oyo East, Afijio, Atiba and Ibarapa East LGAs • RTC related to speed violations: Oluyole, Ona Ara and Ibadan South East LGAs • RTC related to mechanical faults: Oluyole, Ona Ara, Lagelu, Ibadan South East and Egbeda LGAs
Rukewe, Taiwo et al. 2014 (51)	Oyo State, Nigeria	University College Hospital Emergency Department Trauma Registry; 01/ 2011-06/2011	RTCs; 600 crashes	Global and Anselin's Local Moran's I, Getis-Ord Gi, LGA-level analysis	• RTC: the metropolis • Motorbike RTC: metropolis • Motor vehicle RTC: along highways including Ojoo-Moniya axis of the Lagos-Ibadan express road, Iwo road interchange, Akinyo street, Bishop Akinyele road, Parliament road, Queen Elizabeth road, Oba Salawu Aminu roads, Oba Adebimpe road, Fajuywe road
Waldon, Ibingira et al. 2018 (178)	Moshi, Tanzania	Police records of RTC/RTIs; primary data from questionnaire of high road utilizers	RTCs; 279 RTCs	Kernel Density Estimation	• RTC: Market Street and around a heavy traffic downtown interesection and near the northern part of the downtown area, close to Kilimanjaro road and Sokoine road
Ouni and Belloumi 2019 (180)	Center East Region, Tunisia	National Observatory for Information, Training, Documentation and Studies on Road Safety collision database; 2001-2013	Vulnerable road user RTIs and RTFs; 1922 RTCs, 1886 RTIs, 547 RTFs	Ripley's K-function, Kernel Density Estimation - for VRU crashes during the daytime, night-time, morning rush hours, afternoon rush hour, working days, and non-working days)	• RTI/RTF: Sousse and Sfax counties along national and regional highways • Night-time RTI/RTF: Sousse and Sfax • Rush-hour RTI/RTF: Sousse and Sfax near major highway entrances • Working day RTI/RTF: urban and rural areas of Sousse and Sfax and in rural areas of Mahdia • For non-working day RTI/RTF: rural areas of Sousse, Sfax, and Monastir
Hayidso, Gemeda et al. 2019 (44)	Hosanna Town, Ethiopia	Hadiya Zone and Hosanna Town Traffic Police Department, Hadiya Zone and Hosanna Town Transport Authority; 2015-2017	RTCs, severity index; 241 RTCs	Descriptive	• In 2015- RTC: Addis-Ketema sub-town near Ashame Hotel • In 2016- RTC: Wachamo University and Colonel Bezabeh Petros Square • In 2017- RTC: Hosanna town
Tola and Gebissa 2019 (175)	Kombolcha-Dessie Road, Ethiopia	Traffic police commission of Ethiopia; 2012-2016	RTC counts, severity index; not reported	Getis-Ord Gi*	• RTC: roundabout located in Kombolcha town, followed by Dessie town Tita Curve
Aderamo 2012 (41)	Nigeria	The Nigerian Police Force Headquarters and the Federal Road Safety Commission; 2004-2007	RTCs, RTIs, RTFs (counts); not reported	Descriptive, state-level	• RTIs: Benue, Kaduna, and Ogun[C] • RTFs: Benue and Ogun[C]
BakamaNume 2006 (42)	Uganda	Uganda Statistical Abstract (including number of vehicles on roads, accidents, and accident statistics; 1997 -2002	RTC and RTF counts; not reported	Descriptive, district-level	• RTFs: The southern part of the country [C]
Atubi 2012 (43)	Lagos State, Nigeria	the Nigerian Police Force Headquarters and the Federal Road Safety Commission; 1970-2001	RTIs; 726,383 RTCs, 596,425 RTIs, 208,665 RTFs	Descriptive, LGA-level	• RTIs: Ikeja, followed by Lagos mainland, followed by Lagos islandand Ajeromi/Ifelodun[C]

Sukhaia and Jones 2013 (179)	South Africa	National Department of Transport; 2002-2006	RTF count; RTF rate per 100,000 population; not reported	Multilevel negative binomial regression model, police area level	• RTFs: Rustenberg in the North West Province[C]

A. Only for analyses which were conducted on a specific geographic area within the study site (i.e., state-level for an entire country)

B. Only statistically significant results presented, unless specificized

C. Significance not reported

<u>Section 2: What is known about context-specific and multi-level factors that influence crash severity in Africa?</u>

A total of 21 studies assessing factors influencing crash severity in Africa were conducted from 2000 to 2022. Detailed findings are presented in *Table 3.* Most studies took place in Ethiopia (n=4) (78, 181, 182, 183) followed by Ghana (n=3) (79, 184, 185). Six studies utilized data from hospitals or surveys conducted in hospitals (181, 182, 186, 187, 188, 189), while others utilized police/administrative crash databases (42, 46, 79, 80, 81, 83, 184, 185, 190, 191). Several studies focused on specific populations or types of RTCs including with motorcycles (79, 80, 81, 82), rear end RTCs (192), vulnerable road user RTCs (78, 83), and public transport (inter-city buses) RTCs (185). In terms of analysis, most studies used a multinomial logistic regression (78, 80, 81, 83, 184, 185, 191), followed by ordinal logistic regression (183, 190, 193).

Several statistically significant factors were identified. For ease of reporting, we have categorized the findings into three categories of the Haddon's Matrix (194): human factors; vehicle factors; and environmental factors. Studies which assessed factors related to a crash resulting in a fatality found that human factors such as limited education (78), being male (78, 83, 185), and being a vulnerable road user (78, 81, 176, 185, 186, 195) contributing to risk. Motorcyclists not using a helmet was associated with increased risk of RTFs in two studies (81, 189) whereas motorist dangerous behaviour (being unlicensed, speeding, hazardous overtaking) was shown in others (81, 83, 185). For fatalities, vehicle factors included heavy vehicles increased risk (78, 183, 185). Environmental factors included high speed roads (78) and night-time conditions (78, 183, 185, 195). One study found higher fatality risks on roads with village settlements (184) whereas another found higher risk of RTFs in open country roads outside of cities and towns (195).

For studies which assessed factors related to injury or severe injury, human factors included being a poor urban resident (193), being a young driver (191), limited education (181), having multiple injuries (181, 182), not wearing a helmet (182), being a vulnerable road user (187), and engaging in dangerous motorist behavior (speeding, violations (80, 191). Vehicle risk factors included heavy vehicles (182, 189, 191), shared taxis (83), and passenger vehicles (191). Environmental factors include areas with high income inhabitants (78), being transported by an ambulance (181) night-time (182, 187), rainy weather (187), weekends (80), asphaltic roads (42, 46) and curved roadways. Some contradicting findings included one study finding higher risk of injury in the summer (83) whereas another found a greater risk of night-time RTIs during winter (191).

Table 3: Studies on context-specific and multi-level factors that influence crash severity in Africa (2000-2022) (n=21)

Title	Data Source; Period of data collection	Population	Location	Type of Analysis	Outcome	Human factors[A]	Vehicle[A]	Environment[A]
Tulu, Washington et al. 2017 (78)	Road traffic crash data collected by Addis Ababa Police Commission and ten sub-city police departments; July 2009-June 2012	All pedestrians involved with crashes, injuries, and deaths reported by police	Addis Ababa, Ethiopia	A multinomial logistic regression to model injury severity	RTFs	Less educated driver, male pedestrians	heavy vehicles, minibuses/buses Vehicle: trucks	High speed roads, intersections, nighttime
					RTIs		Trucks	Areas with high income inhabitants
Boniface, Museru et al. 2016 (189)	Cross-sectional survey at hospitals; April 2014-September 2014	4,675 patients involved with motor traffic crashes	Muhimbili Orthopedic Institute, Ilala Hospital, Mwananyamala Hospital and Temeke Hospital in Tanzania	Chi-squared tests	RTFs	18-25 years of age, multiple injuries, severe injuries, not using helmet		Transport by police vehicles to hospital, health access within 2-10 hours
Kraemer 2021 (193)	Demographic and Health Survey; 2016	Not specified	Uganda	Ordinal logistic regression and output converted to adjusted probabilities using predictive margins	RTI	Poor urban residents		
Gebresenbet and Aliyu 2019 (181)	Survey at hospital; June 3 –August 13, 2018	Patients involved in RTC	Tirunesh Beijing hospital in Addis Ababa, Ethiopia	Bivariate and multivariate logistic regression	RTI	'Can read or write' educational status, sustaining multiple injuries, sustaining multiple injury types		Being transported by ambulance from the scene
Baru, Azazh et al. 2019 (182)	Survey at hospital; March 1 to May 10, 2017	363 patients with road traffic injuries	Tikur Anbessa Specialized Teaching Hospita, St. Paul Millennium Medical College and Hospital, and All Africa Leprosy,Tuberculosis, Rehabilitation and Training Center Hospital in Addis Ababa, Ethiopia	Bivariate and multivariate logistic regression	RTI	Multiple injuries, not wearing a helmet	Large/heavy vehicle, traveling unrestrained on the back of a tuck	Nighttime
Abegaz, Berhane et al. 2014 (183)	Detailed incident investigations, interviews with eyewitnesses, and reviewing medico-legal reports; June 2012 to July 2013	819 RTCs	Addis Ababa to Hawassa Highway, Ethiopia	Generalized ordered logistic/partial proportional odds model	RTF	Alcohol use, falling asleep when driving	Mini-bus or van	Driving at night in the absence of streetlight, rain

Mphekgwana 2022 (190)	The Department of Roads and Transport in Limpopo Province; January 2009-December 2015	18, 039 RTCs	Limpopo Province, South Africa	Generalized ordered logistic regression	RTI			Potholes, driving on district roads
Van Hoving, Hendrikse et al. 2014 (188)	Survey at hospitals; June 1 2012-August 31 2013	107 occupants of vehicles involved in RTCs	Groote Schuur Hospital, Tygerberg Hospital, G F Jooste Hospital, New Somerset Hospital, Victoria Hospital and Red Cross War Memorial Children's Hospital in Cape Town, South Africa	Chi-squared test	RTI	*No difference between use of seatbelts and severe injury*		
Salum, Kitali et al. 2019 (81)	Motorcycle crash data; 2013-2016	783 motorcycle RTCs	Dar es Salaam, Tanzania	Multinomial logistic analysis	RTF	Speeding, DUI, motorcyclists without helmets, being a young rider		
Osoro, Ng et al. 2011 (187)	Semi-structured survey at the hospital; August 10 2009-November 15 2009	300 RTC victims	Thika hospital, Kenya	Multivariate logistic regression	RTI	Vulnerable road users		Rainy weather, nighttime
Damsere-Derry, Adanu et al. 2021 (185)	Building and Road Research Institute's (BRRI) accident database; 2013-2017	1364 RTIs and RTFs related to public transport	Accra-Kumasi-Sunyani-Gonokrom highway, Ghana	Random parameters multinomial logistic regression	RTF	Being 60 years or above, being a pedestrian, being male, being unlicensed, driving too fast, wrong overtaking, careless driving, inexperienced driving	Large buses or minibuses	Type of crash (sideswipe, head on collision) being in a crash where driver is a fatality, between 6 pm and midnight
Kitali, Kidando et al. 2022 (80)	Motorcycle crash data; 2013-2016	704 motorcycle RTCs	Dar es Salaam, Tanzania	Bayesian multinomial logistic model with A Dirichlet random effect to account for unobserved and missing variables in data	RTF	Speeding, impaired riding, violation (wrong way, signal violation)		Road class (medium speed/collector roads), weekends, off-peak hours, impact type (head on crashes)
Zhang and Hassan 2019 (191)	Not specified; 2010-2016	746 nighttime RTCs; 634 daytime RTCs	Long term highway work zone, Egypt	Mixed multinomial logistic model	Nighttime RTIs	Younger driver, male driver, U-turn crashes, speeding	Passenger vehicle, multiple vehicles, angled collisions	Curved roadways, rural areas, rainy conditions, winter season, closure of many lanes
					Daytime RTIs	Younger driver	Heavy vehicle, passenger vehicle	Curved roadways, rural areas, weekday

Ouni and Belloumi 2018 (83)	National Observatory for Information, Training, Documentation and Studies on Road Safety collisions database	860 RTCs with VRUs	Central-East Region, Tunisia	Multinomial logistic model	RTF	Male, change of direction, hazardous overtaking:		
					RTI	Tunisian national	Shared taxis	Summer, on a national highway
Wahab and Jiang 2019 (184)	Building and Road Research Institute's (BRRI) accident database; 2011-2015	8,516 motorcycle RTCs	Ghana	Multinomial logistic model	RTF		Heavy vehicle and motorcycle	At a junction, on a weekend, on a tarred and good surface road, at traffic control, on roads within village settlements
Tamakloe, Das et al. 2022 (79)	Building and Road Research Institute's (BRRI) accident database; 2016 to 2018	260 motorcycle RTCs	Greater Accra Region, Ghana	Binary logistic model; association rule mining	RTF	Age less than 30 years old		
					RTI	Unknown license status		T junction, no median
Adanu, Riehle et al. 2020 (195)	National Road Safety Council; 2010-2012	4,127 RTCs	Namibia	Mixed logistic modelling	RTF	Pedestrians		Ran off crashes, dark unlit roadways, open country outside of cities and towns, head on collisions
McGreevy, Stevens et al. 2014 (186)	Hospital surveillance data; April 15- October 15 2009	1,686 RTIs	Central Hospital of Yaounde, Cameroon	Chi square test for dichotomous variables and the Wilcoxon rank sum test for continuous variables	RTF	Being a motorcyclist, lower economic status		
Zhang and Hassan 2019 (192)	The Ministry of the Interior database of national road crashes; 2010-2017	1,045 rear end RTCs	Long-term highway work zone projects, Egypt	Random-parameter ordered probit model	RTF	Heavy vehicles driving at high speeds through work zones at night[B] Young male drivers who travel at nighttime during weekends[B] Vehicle occupants in rural work zone areas and horizontal curves[B]		
Patel, Krebs et al. 2016 (176)	Kigali Traffic Police data; 2013	2,589 RTCs	Kigali, Rwanda	Multivariate logistic regression	RTF	Motorcycles, pedestrians		
Akinyemi 2019 (46)	Federal Road Safety Corps crash database; 2011	RTCs, unknown number	Nigeria	Geographically weighted regression	RTF			Length of asphaltic roads
BakamaNume 2006 (42)	Uganda Statistical Abstract; 1997 -2002.	RTCs, unknown number	Uganda	Not specified	RTIs			Level of urbanization in districts, number of tarmac kilometers in the district
					RTFs			Number of tarmac kilometers in the district; level of urbanization in districts

A. Only statistically significant results presented

B. Study reported only combinations of factors

Section 3: What is known about community (i.e., road user) perspectives on RTC, RTIs, and RTFs in Africa?

A total of 10 qualitative studies with road users have been conducted in Africa from 2000 to 2022. Detailed findings by study are presented in *Table 4.* The ten studies were conducted in Tanzania (104, 106), Nigeria (108, 110), Kenya (107), Namibia (196), South Africa (109), and Ghana (101, 102, 197). A diverse range of participants were studied, including studies focused specifically on pedestrians (101, 106), commercial drivers such as motorcycle drivers (108, 110), mini-bus drivers (107), and taxi drivers (109), and people who had experienced RTCs or RTIs (104, 196, 197). Nearly all studies conducted in-depth interviews (n=9) with one conducting focus groups of RTI victims, families, and community advisory board members (104).

Half of studies (n=5) assessed experiences, causes, and factors associated with RTCs and RTIs (101, 102, 103, 107, 109, 196), whereas others focused on specific risks such as drink-driving (104) and psychoactive drug use (110). One study interview pedestrians to understand their views on pedestrian bridges in Dar es Salaam, Tanzania (106). For studies which focused on experiences of injury among victims, there were negative experiences such as mental health issues post-crash and a lack of psychosocial support, and positive experiences related to social support from families and groups (103, 105). There were several studies which found themes relating to risky road user behavior, including drink-driving among motorbike taxis (104), drug use among commercial drivers (110), jaywalking among pedestrians (101, 106), and speeding/unsafe driving among motorists (102, 109). Themes related to higher level factors (environment, policy) were noted, such as poor road conditions and traffic signs (110), narrow roadways (101), traffic congestion limiting access to post-crash care (107), and corruption/lack of enforcement (102, 104). A study inquiring about views on pedestrian bridges found that pedestrians spoke highly and positively on citizen participation and involving local people in the design and plan of road safety interventions. Participants recommended education efforts to increase usage of bridges and made suggestions for improving issues with pedestrian bridges (i.e., proliferation of socioeconomic activities in proximity, crowding, lack of lights at night, and the infrastructure which requires a certain level of fitness) (106).

Table 4: Studies on road user perspectives on RTCs, RTIs, and RTFs in Africa (2000-2022) (n=10)

Study	Geography	Population	Data collection; period of data collection; data analysis method	Objective	Themes
El-Gabri, Barcenas et al. 2020 (104)	Moshi, Tanzania	104 participants including RTI victims, families, and community advisory board members	Semi-structured focus group; not specified; inductive grounded theory and thematic analysis	Perceptions of drink-driving and RTIs	Drinking is engrained in motorbike ('boda boda') culture and is very common; passengers [not drivers] are responsible for their own safety; it is a citizen's duty to report suspected drink-driving to police, although enforcement may not always be effective
Chatukuta, Groce et al. 2021 (105)	Windhoek, Rehoboth, Swakopmund, Walvis Bay, Namibia	14 RTI victims; 20 healthcare workers	Semi-structured in-depth interviews; 02/2017 to May 2017; inductive grounded theory	Experiences of RTIs among victims	Widely reported mental health issues related to RTI; family/friends, wheelchair support groups, WhatsApp groups and motivational speaking helped with coping HCWs: lack of psychological support for RTI survivors in Namibia, specifically a lack of psychologists and counselors,
Katopola, Mashili et al. 2022 (106)	Dar es Salaam, Tanzania	19 pedestrians at pedestrian bridges	Semi-structured in-depth interviews; 01/2019-03/2019; inductive phenomenographical approach	Views on pedestrian bridges	Limited citizen participation, advantage to including local people in planning and design; awareness initiatives may encourage usage; emerging socioeconomic activities around the bridge; safety concerns at night; crowding; lengthy time/distance required to cross; fitness required to use bridge; easy to understand use and purpose
Dotse, Nicolson et al. 2019 (102)	Greeter Accra, Ashanti, and Volta Region, Ghana	20 commercial drivers of passengers	Semi-structured in-depth interviews not specified; inductive open coding	Factors contributing to RTCs	Work pressure (e.g., revenue pursuit; fatigued driving); violations, concentration (e.g., mobile phone use), training (e.g., ability to interpret road signs), behavior of other road users and corruption (e.g., improper licensing)
Teye-Kwadjo 2017 (101)	Lower Manya Krobo, Ghana	26 pedestrians (people not possessing driver's license)	Semi-structured in-depth interviews; not specified; inductive thematic analysis	Determinants of RTIs	Behavioral factors such as jaywalking, inconsiderate driving, cell phone use while walking, roadside trading; personal factors such as low pedestrian risk perception, inaccurate vehicle speed estimation, pedestrian and driver attitudes to right-of-way laws; and environmental factors such as narrow roadways, no sidewalks, footbridges, and unsignalized crossings
Raynor and Mirzoev 2014 (107)	Kenya	10 mini-bus ('matutu') drivers	In-depth interviews and unstructured observations; not specified; deductive thematic analysis	Causes of RTCs	Pre-crash factors include driver error, unwillingness of passengers to speak out, enforcement, road safety attitude, impairment of drugs/alcohol, roadworthiness of vehicle, enforcement of speed cameras, road condition, speed limits, pedestrian areas. During crash factors include use of seatbelts, driver error, availability of seatbelts, safety devices, and roadside barriers. Post-crash factors include willingness to administer first aid, accessibility of health facilities, fire risk, and traffic congestion
Sanusi and Emmelin 2015 (108)	Ibadan, Nigeria	10 commercial motorcycle riders	In-depth interviews; not specified; inductive content analysis	Perceptions of risk	Risk-taking among riders is generally acceptable (e.g., inadequate training, poor enforcement); risk-taking is an intrinsic part of the occupation (e.g., unavoidable accidents; constant exposure); risk-taking as a way to make ends meet (e.g., family responsibility; unaffordable safety measures)
Wilson, Dzansi et al. 202 (103)	Accra, Ghana	13 RTC survivors	In-depth interviews; 28/09/2018-05/11/2018; a deductive analysis based on Carlson and Dalenberg framework	Experiences of RTC survivors	Cognitive experiences such as intrusive thoughts and images, nightmares, depersonalization; affective responses such as anxiety and fear, sadness and crying, resentment; social experiences such as rejection, withdrawal for fear of stigma, and social support.
Peltzer and Mashego 2003 (109)	Limpopo Province, South Africa	10 taxi drivers, 8 truck drivers, 20 motorists, 15 policymakers/law enforcement, 25 passengers/pedestrians	In-depth interviews; not specified; deductive content analysis	Perceived causes of RTIs	Legislation and law enforcement; excessive speeding and overloading; road and substance use; unacceptable driving behavior; roadworthiness of vehicle; aging, disease, and disability, fatigue and acute psychological stress; cultural/religious factors; traffic signs and road conditions

Nelson, Umoh et al. 2018 (110)	Uyo, Nigeria	94 commercial tricycle riders	In-depth interviews; not specified; inductive and deductive thematic analysis	Perception of psychoactive drug use and risk of RTCs	Drug use of a variety of licit and illicit drug use was common; risk of RTCs when consuming psychoactive drugs was recognized; interventions such as education on the negative consequences, screening for drug use, and reducing wide availability

CHAPTER 2 APPENDIX

Data variables collected by the BRRI

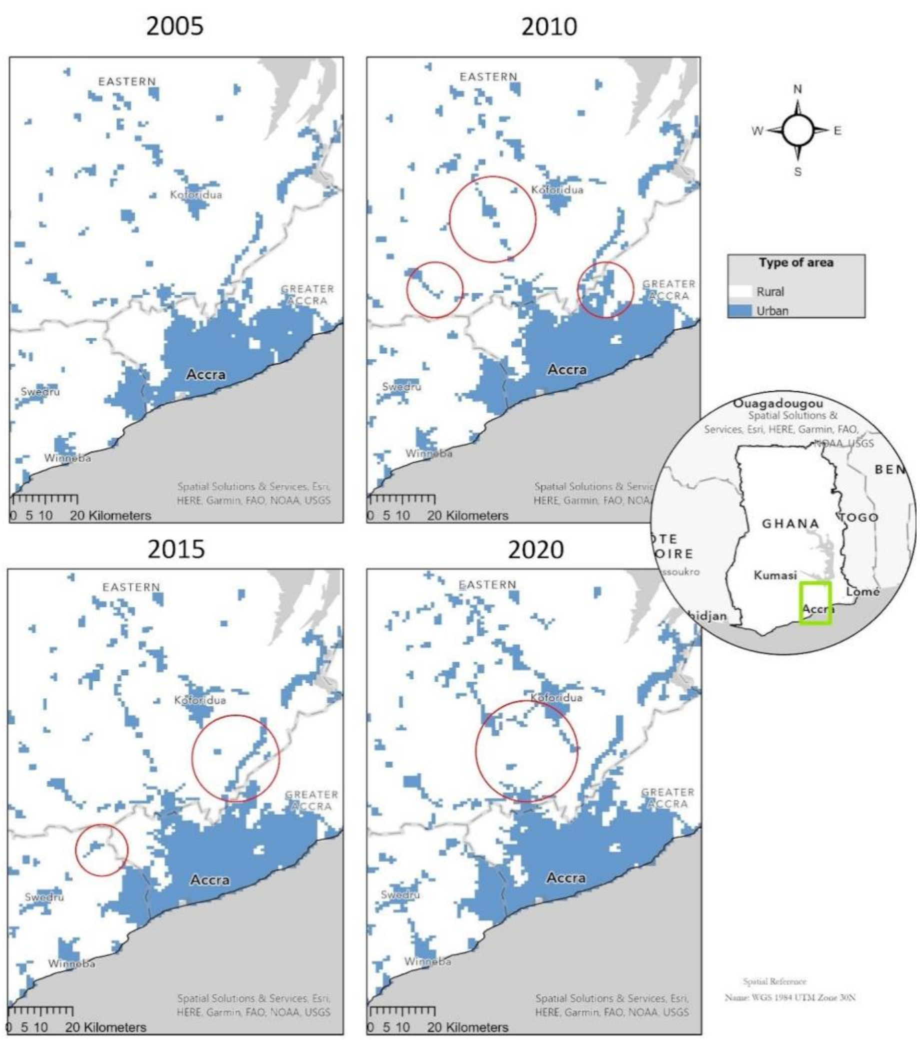
Haddon's Matrix	Factor	Categories and/or *description*
Environment	Geography (region, town, police department)	*Reports the geography*
	Time (day of week, date, time)	*Reports the time, day, and date*
	Road number	*Reports the national, inter-regional, and regional road number assigned by the GHA*
	Kilometer marker	*Reports the precise 100-meter location along the road where the collision took place*
	Light conditions	Night- no lights; Night- lights off, Night-lights on
	Road description	Straight and flat; curve only incline only; curve and incline; bridge
	Road surface type	Tar good; Tar few potholes; tar many potholes; gravel; earth, few potholes
	Shoulder type	Tarred; untarred; no shoulder
	Shoulder condition	Good; poor; overgrown; no shoulder
	Road separation	Median; no median
	Surface condition	Dry; wet; muddy
	Surface repair condition	Good; potholes; rough
	Road type	Motorway; highway; urban road; feeder road; other roads
	Type of junction	Traffic circle; T-junction; Y-junction
	Traffic control	None; pedestrian crossing; signals; stop sign; give way; other
	Roadworks	At roadworks; not at road works
Vehicle	Type of vehicle	Car; HGV; tractor; bus; minibus; motorcycle; pick up; bicycle; tricycle; rickshaw
	Maneuver	Right turn; left turn; U-turn; cross traffic; merging; diverging; overtaking; going ahead; reversing; sudden start; sudden stop; parked off road; stopped on road
	Vehicle damage	None; minor; extensive
	Defects	None; brakes, steering; tires; suspension; lights; multiple; other
Human	Sex	Male; female
	Age	
	Driver nationality	Ghanaian; other African; Asian; European/north America; other
	Type of road user	Driver; passenger; pedestrian
	Driver license status	Full; provisional; learner; unlicensed

	Drinking and driving	Not suspected; suspected; tested and positive; tested and negative
	Drink/drug	Not suspected; suspected; unknown
	Driver error	None; inexperienced; inattentive; too fast; too close; no signal; improper overtaking; improper turning; fatigued/asleep; other
	Passenger position	Front seat; rear seat; motorcycle passenger; bus passenger; inside; outside sitting; outside standing
	Passenger action	Boarding; jumping; falling from vehicle; other
	Pedestrian action	No action; crossing road; walking along road; walking along edge; playing on road; on footpath; other

Additional information related to urban-rural stratification

We found only minor changes in the spatial distribution of urban/rural areas across the two decades of the data (2005 to 2020) on a national level, despite notably increased urbanization rates and urban sprawl in specific areas (e.g., Accra) (27). The below figure shows some small areas that changed from rural to urban during the study periods (newly urban areas compared to the prior period are denoted in the red circles). Given these changes, we selected the most recent period of data to our four-year period to determine appropriate areas (e.g., 2005 for the 2005 to 2008 period).

Degree of urbanization in Ghana (2005, 2010, 2015, 2020)



Additional information for the selected distance threshold

The urban/rural stratification informed the distance threshold test specification, which is the distance at which indices would be considered neighbors in the analysis. For rural areas, we deemed 1,000 meters appropriate as a high-risk area (particularly considering the high-speed limits on major roads in rural areas). In contrast, the same 1,000 meters may be heterogeneous in terms of population density, land use, and other characteristics in an urban area and, therefore, not appropriate. Thus, for urban areas, we used a threshold of 300 meters. These distances were selected by consulting with in-country experts and conducting exploratory data analyses in ArcGIS Pro. For the latter, we used the 'Incremental Spatial Autocorrelation' tool in ArcGIS Pro, which runs several Moran's I spatial autocorrelation tests to understand the spatial clustering at increasing distances. We present results for this test for 2017 to 2020 (presented in the table below) The results demonstrated that statistically significant spatial clustering occurs at ~ 200 meters and remains significant for all subsequent distances tested (until two km). Results were similar for the earlier periods and when stratifying for urban and rural areas (data not shown), indicating that the selected distance thresholds were appropriate.

Global Moran's I Spatial Autocorrelation Results (2017 to 2020 Injury Severity Indices)

Distance	Moran's Index	Expected Index	Variance	z-score	p-value
100	0.007875	-0.000422	0.000744	0.304119	0.761037
200	0.053532	-0.000235	0.000326	2.979841	0.002884
300	0.041539	-0.0002	0.000231	2.74813	0.005994
400	0.042928	-0.000184	0.000185	3.171033	0.001519
500	0.03744	-0.000174	0.000157	3.005308	0.002653
600	0.042802	-0.000168	0.000139	3.644929	0.000267

700	0.041763	-0.000163	0.000126	3.736146	0.000187
800	0.038776	-0.000159	0.000115	3.631091	0.000282
900	0.035742	-0.000155	0.000106	3.483506	0.000495
1000	0.039854	-0.000153	0.000098	4.04178	0.000053
1100	0.040886	-0.000152	0.000091	4.290705	0.000018
1200	0.049898	-0.00015	0.000086	5.395272	0
1300	0.048464	-0.000149	0.000081	5.392618	0
1400	0.052084	-0.000148	0.000077	5.961398	0
1500	0.059152	-0.000147	0.000073	6.942519	0
1600	0.057943	-0.000147	0.000069	6.970104	0
1700	0.060709	-0.000146	0.000067	7.459923	0
1800	0.060785	-0.000145	0.000064	7.621071	0
1900	0.05806	-0.000145	0.000061	7.466401	0
2000	0.061409	-0.000144	0.000058	8.056814	0

Additional information about the impact of COVID-19

Given that the COVID-19 pandemic occurred in 2020 during the most recent period (2017 to 2020) in the analysis, we chose to assess annual trends in each of the outcomes (MVCs resulting in property damage, minor injuries, severe injuries, and deaths) to determine if there was a substantial change which should influence our analysis decisions. Overall, we found the counts of outcomes in 2020 to be similar to the prior year, indicating that it would be appropriate to aggregate into four-year periods including this time. This may have been a result of the limited lockdowns in Ghana during the pandemic (e.g., only a partial three-week lockdown of Accra and Kumasi).

Yearly sums of motor vehicle collisions resulting in property damage, minor injuries, severe injuries, and deaths (2005-2020)

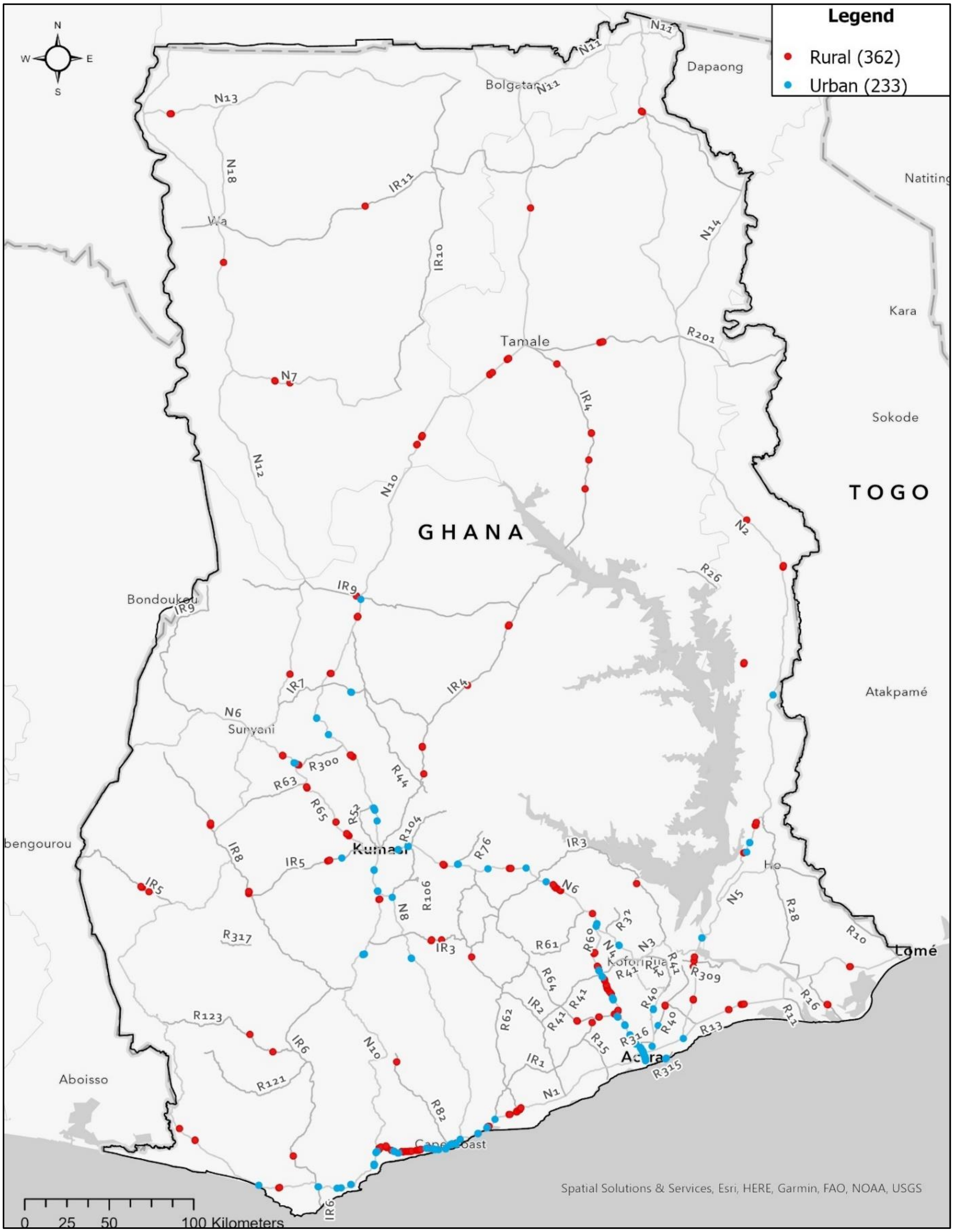
Outcome	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Property damage	1,789	1,834	1,770	1,666	1,696	1,668	1,437	1,728	1,462
Minor road traffic injuries	6,158	5,387	4,870	5,734	6,919	6,210	5,193	4,191	3,976
Severe road traffic injuries	3,658	4,088	4,091	4,025	4,724	4,133	3,870	3,550	3,090
Deaths	1,312	1,328	1,370	1,380	1,739	1,491	1,527	1,506	1,338
road traffic injury severity mean*	5.08	5.51	5.43	5.30	5.87	5.85	5.68	5.68	5.13
Outcome	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**	
Property damage	1,386	792	492	710	783	924	945	21,082	
Minor road traffic injuries	3,920	2,845	1,973	2,483	2,902	2,924	3,305	68,990	
Severe road traffic injuries	3,496	2,565	2,320	3,196	3,731	4,088	4,250	58,875	

Deaths	1,305	1,002	979	1,042	1,181	1,208	1,437	21,145
road traffic injury severity mean*	5.44	5.18	5.62	5.30	5.71	5.88	5.75	5.52

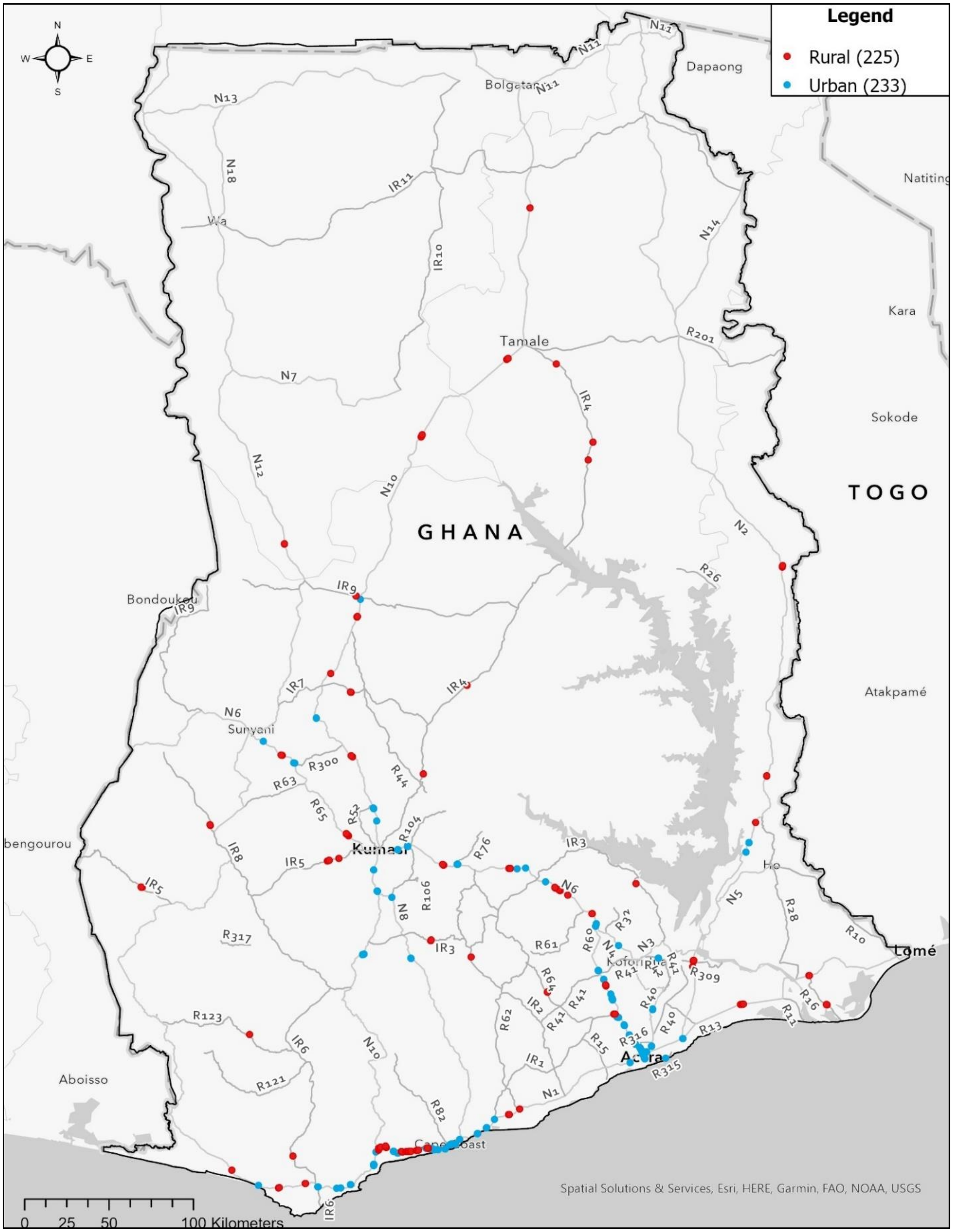
* For 100-meter locations reporting any MVC, minor road traffic injuries, severe road traffic injuries, and death (N=30,939 unique locations)

National maps of rural and urban hot spots for all periods

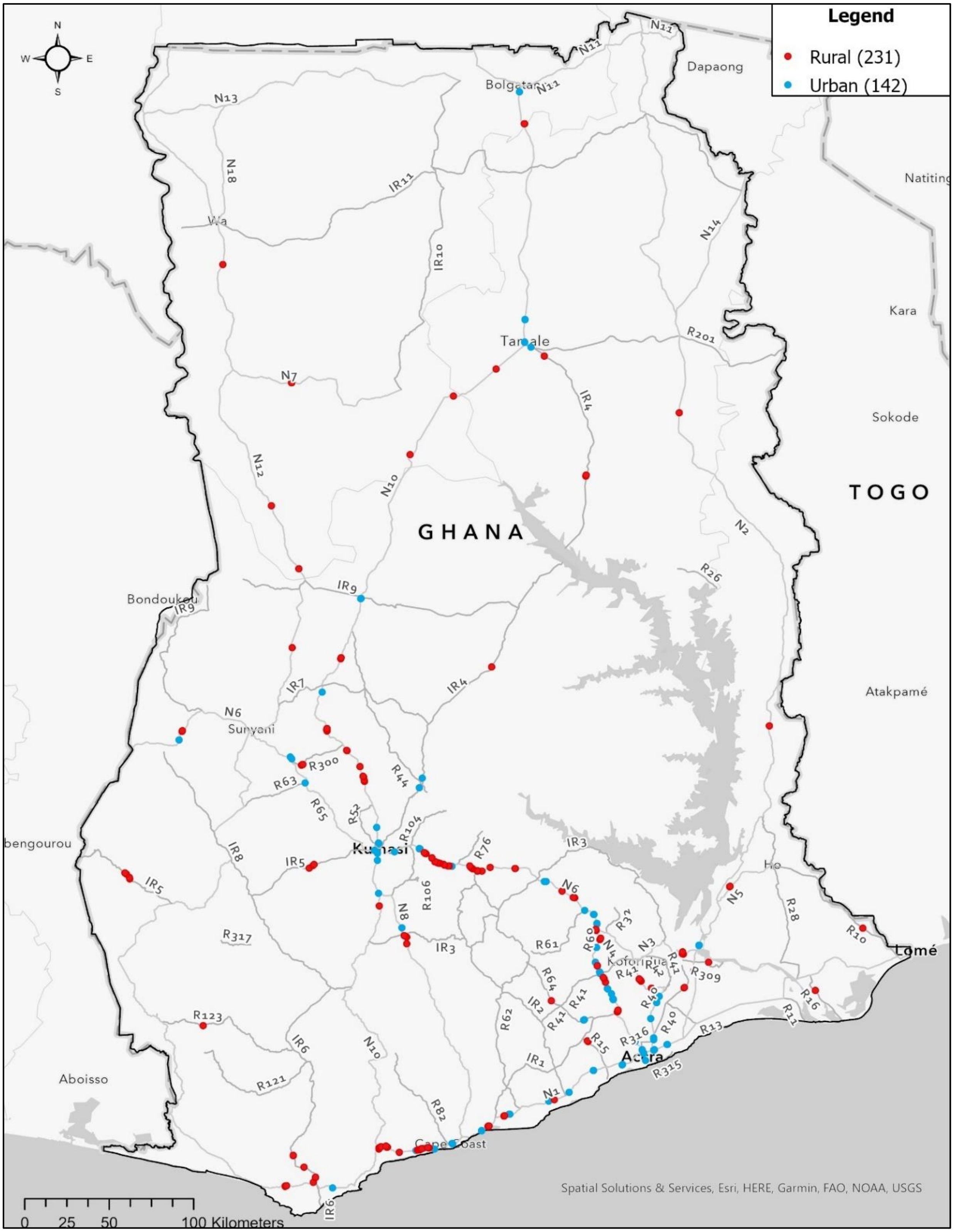
National map of statistically significant hot spots 2005 to 2008



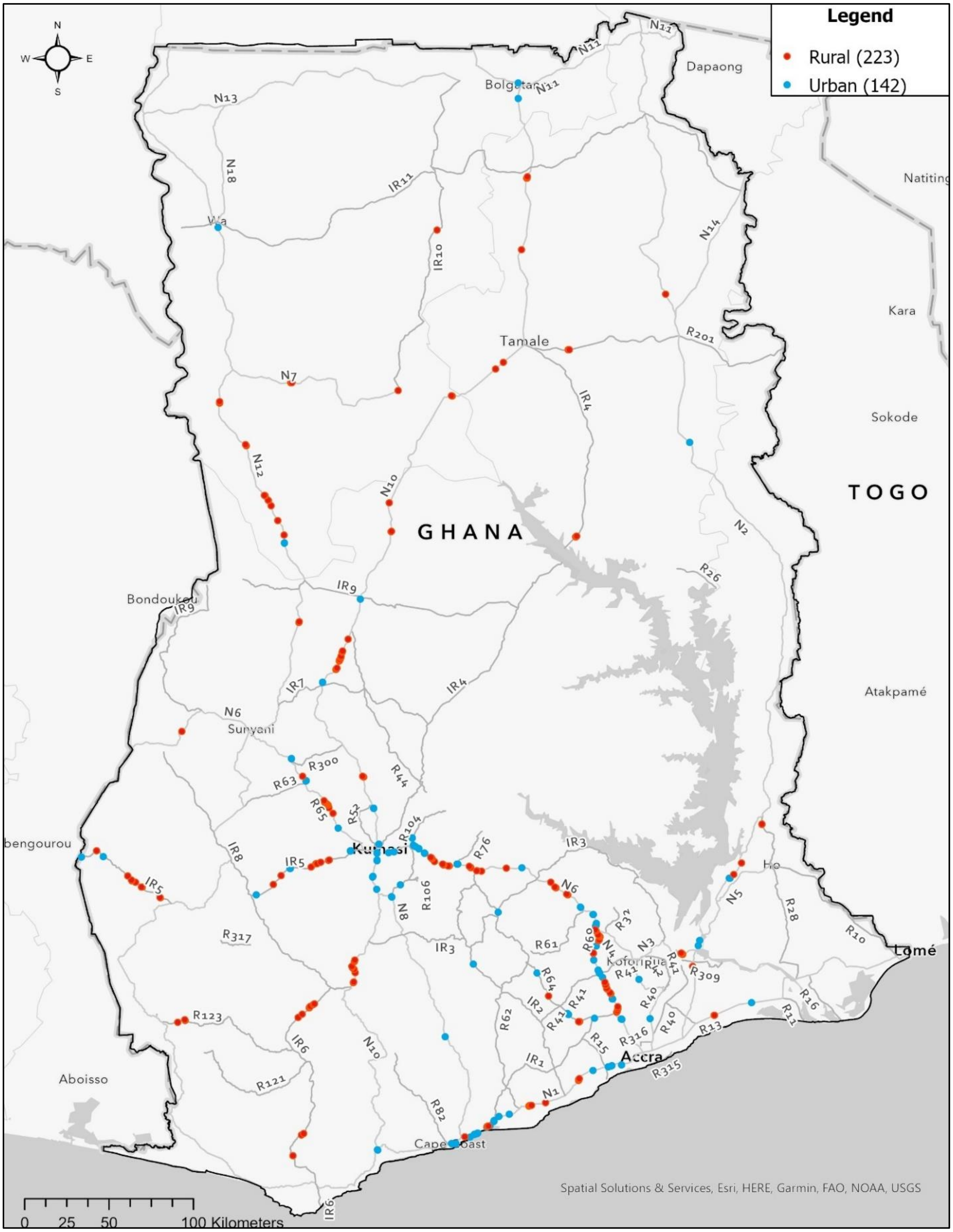
National map of statistically significant hot spots 2009 to 2012



National map of statistically significant hot spots 2013 to 2016



National map of statistically significant hot spots 2017-2020



CHAPTER 3 APPENDIX

Outcome definitions for emerging hot spot analysis tool in ArcGIS Pro

In the following table, we present the pre-defined pattern types and definitions for the emerging hot spot analysis tool in ArcGIS Pro (198).

Pattern type	Definition
New hotspot	A location that is a statistically significant hotspot for the final time step and has never been a statistically significant hotspot before.
Consecutive hotspot	A location with a single uninterrupted run of at least two statistically significant hotspot bins in the final time-step intervals. The location has never been a statistically significant hotspot prior to the final hotspot run and less than 90 percent of all bins are statistically significant hotspots.
Intensifying hotspot	A location that has been a statistically significant hotspot for 90 percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant.
Persistent hotspot	A location that has been a statistically significant hotspot for 90 percent of the time-step intervals with no discernible trend in the intensity of clustering over time.
Diminishing hotspot	A location that has been a statistically significant hotspot for 90 percent of the time-step intervals, including the final time step. In addition, the intensity of clustering in each time step is decreasing overall and that decrease is statistically significant.
Sporadic hotspot	A statistically significant hotspot for the final time-step interval with a history of also being an on-again and off-again hotspot. Less than 90 percent of the time-step intervals have been statistically significant hotspots and none of the time-step intervals have been statistically significant cold spots
Oscillating hotspot	A statistically significant hotspot for the final time-step interval that has a history of also being a statistically significant cold spot during a prior time step. Less than 90 percent of the time-step intervals have been statistically significant hotspots.
Historical hotspot	The most recent time period is not hot, but at least 90 percent of the time-step intervals have been statistically significant hotspots.
New cold spot	A location that is a statistically significant cold spot for the final time step and has never been a statistically significant cold spot before.
Consecutive cold spot	A location with a single uninterrupted run of at least two statistically significant cold spot bins in the final time-step intervals. The location has never been a statistically significant

	cold spot prior to the final cold spot run and less than 90 percent of all bins are statistically significant cold spots.
Intensifying cold spot	A location that has been a statistically significant cold spot for 90 percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is increasing overall and that increase is statistically significant.
Persistent cold spot	A location that has been a statistically significant cold spot for 90 percent of the time-step intervals with no discernible trend in the intensity of clustering of counts over time.
Diminishing cold spot	A location that has been a statistically significant cold spot for 90 percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is decreasing overall and that decrease is statistically significant.
Sporadic cold spot	A statistically significant cold spot for the final time-step interval with a history of also being an on-again and off-again cold spot. Less than 90 percent of the time-step intervals have been statistically significant cold spots and none of the time-step intervals have been statistically significant hotspots.
Oscillating cold spot	A statistically significant cold spot for the final time-step interval that has a history of also being a statistically significant hotspot during a prior time step. Less than 90 percent of the time-step intervals have been statistically significant cold spots.
Historical cold spot	The most recent time is not cold, but at least 90 percent of the time-step intervals have been statistically significant cold spots.
No detectable pattern	Does not fall into any of the hotspot patterns defined below.

Additional information on calculating appropriate distance bands

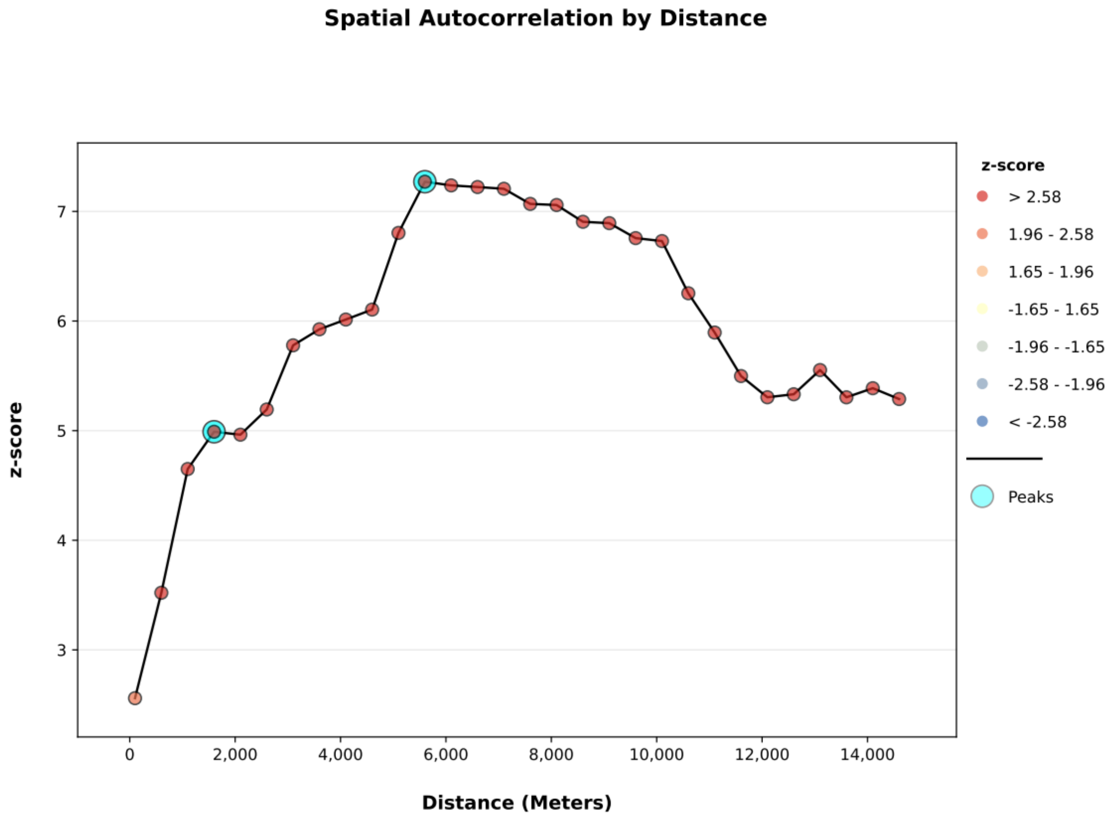
In the following table, we present results from the "calculate distance band from neighbor count" tool in ArcGIS Pro. This determines the distance to the closest eight neighbors and was used to inform our neighborhood designation for the emerging hot spot analysis.

'*Calculate distance band from neighbor count' results (Eight neighbors)*

3-year period	Type of area	Average	Maximum
2006-2008	Rural	4158.83	67977.36
2006-2008	Urban	2137.75	88061.98
2009-2011	Rural	3769.39	60598.66
2009-2011	Urban	2047.36	88136.43
2012-2014	Rural	4520.97	50970.82
2012-2014	Urban	2376.72	93841.96
2015-2017	Rural	5515.24	58322.01
2015-2017	Urban	3709.09	86875.77
2018-2020	Rural	4706.42	52603.80
2018-2020	Urban	2879.49	87856.40

We also conducted incremental spatial autocorrelation tests for each urban and rural area for each three-year period. We present an example of those results for 2006 to 2008 in rural areas below.

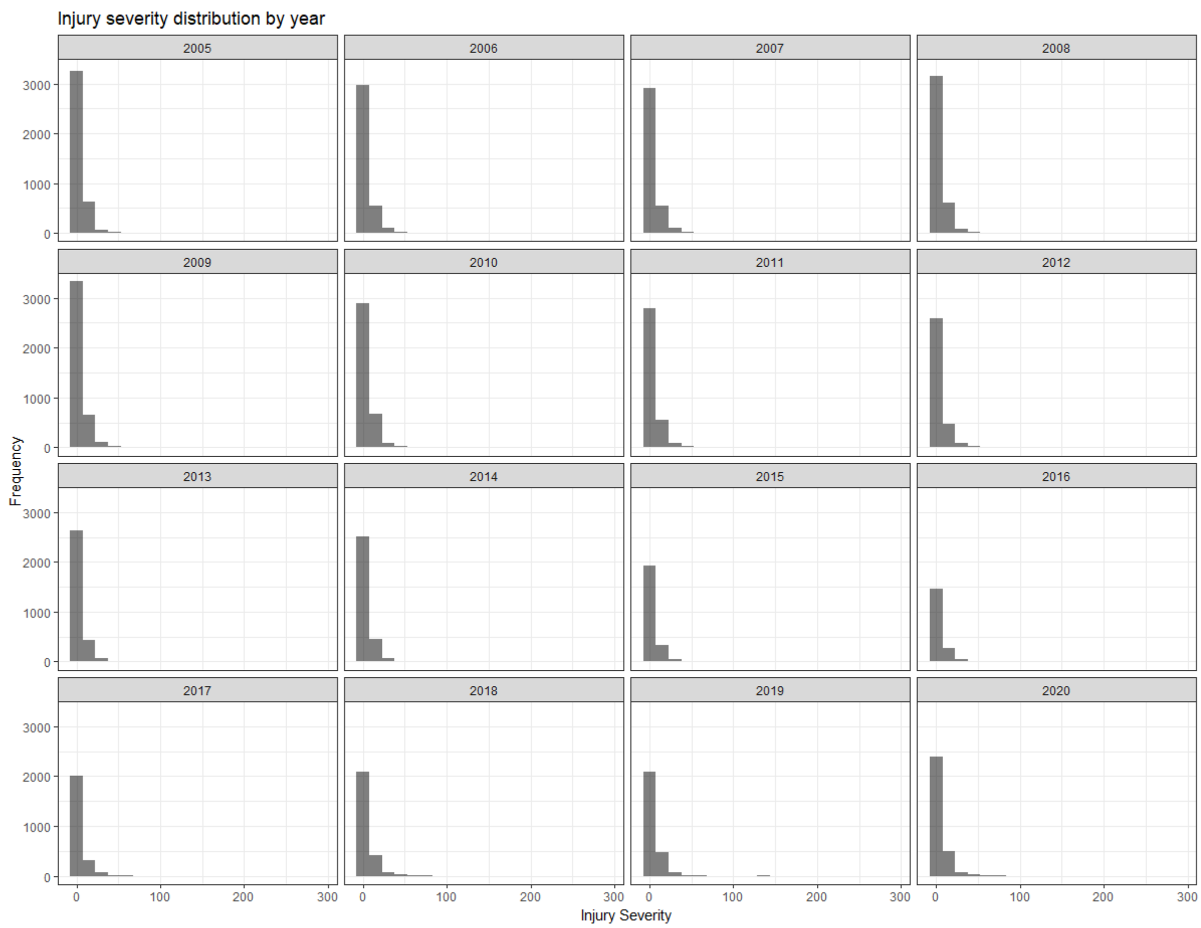
Incremental spatial autocorrelation results – rural areas 2006-2008



<u>Distribution of injury severity index from 2005 to 2020</u>

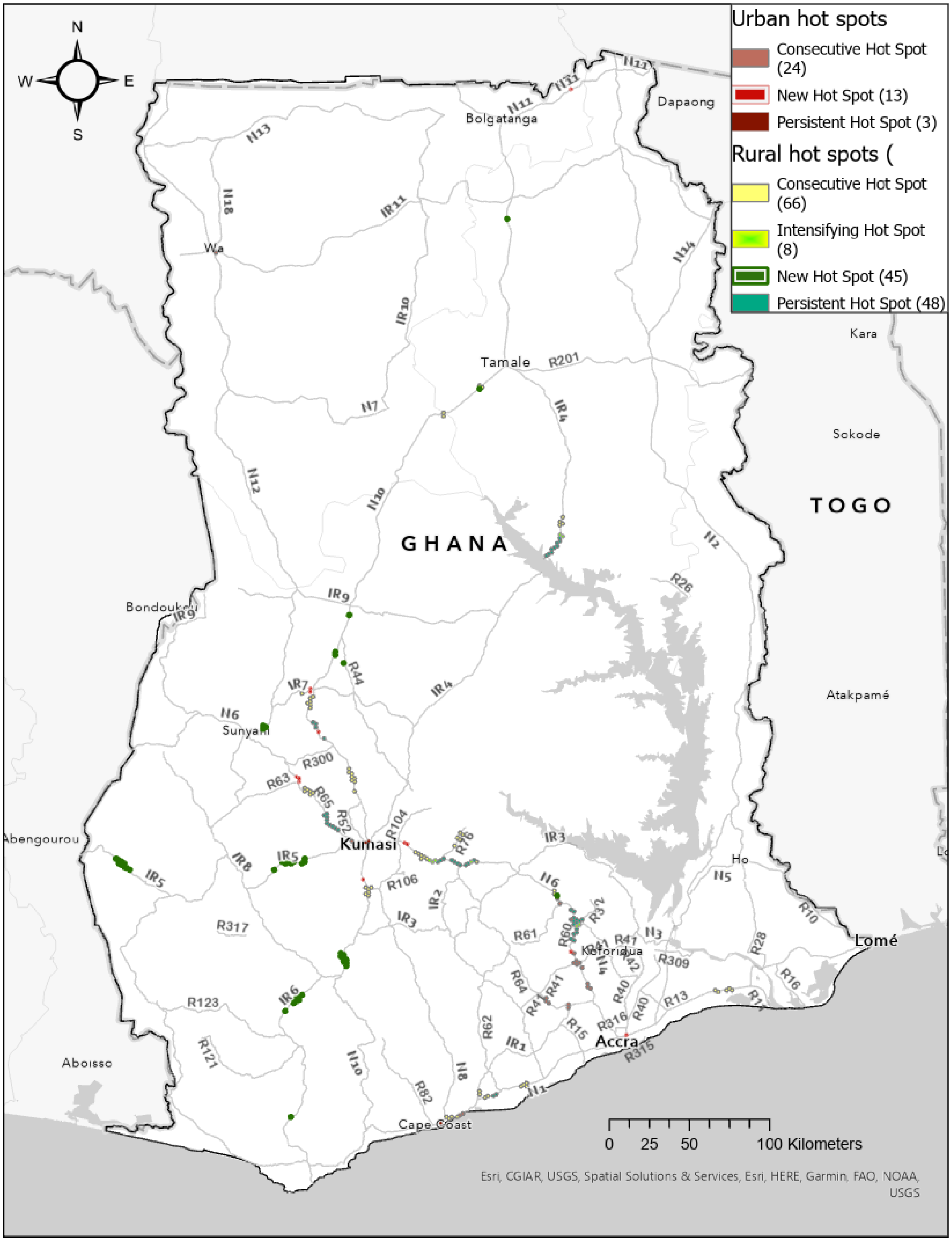
We presented the mean of the injury severity index in the main text. In an effort to understand the potential changes in the distribution, we plotted a histogram for each year, shown below.

Histograms of road traffic injury severity index - 2005 to 2020

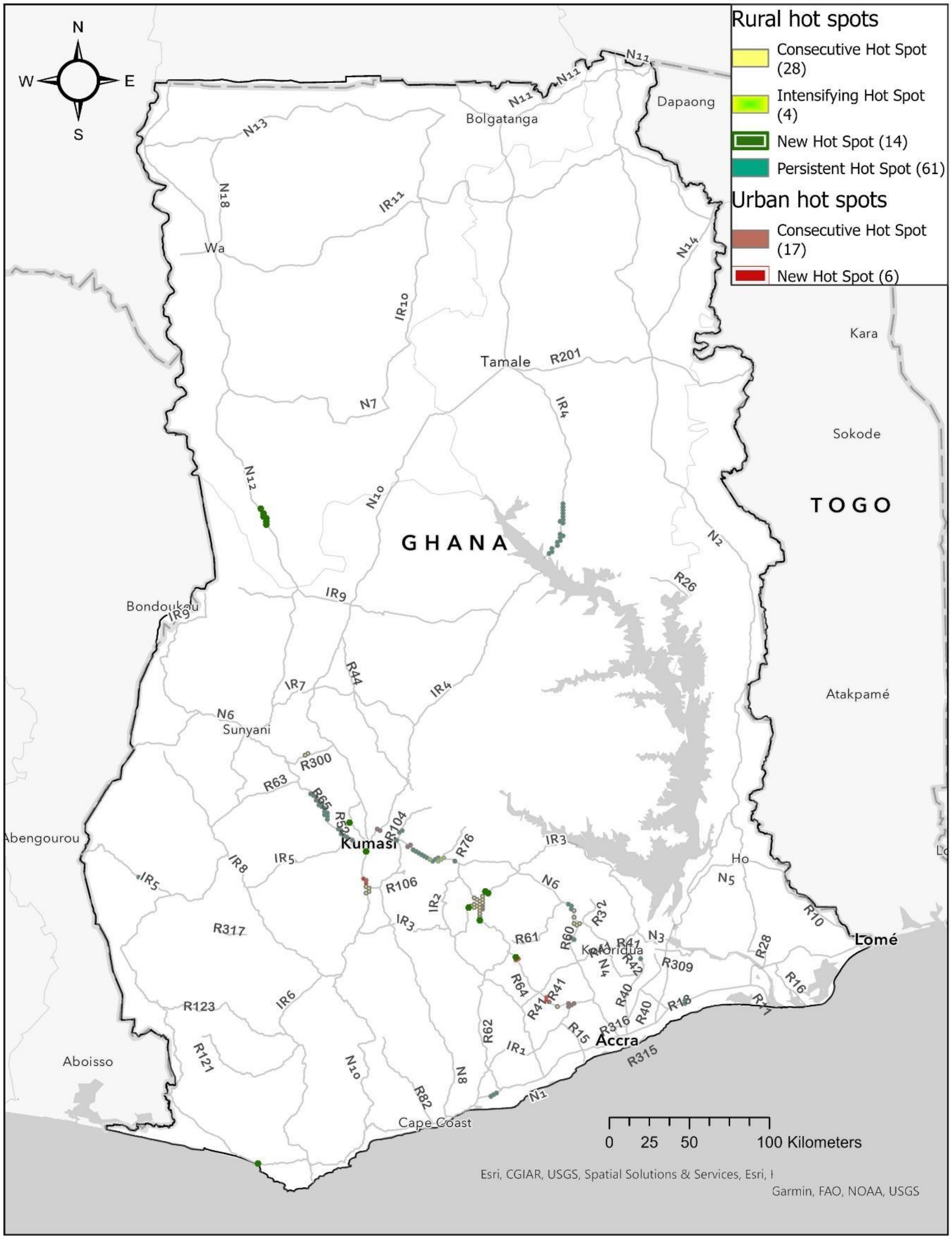


National maps of rural and urban spatiotemporal clusters for by outcome

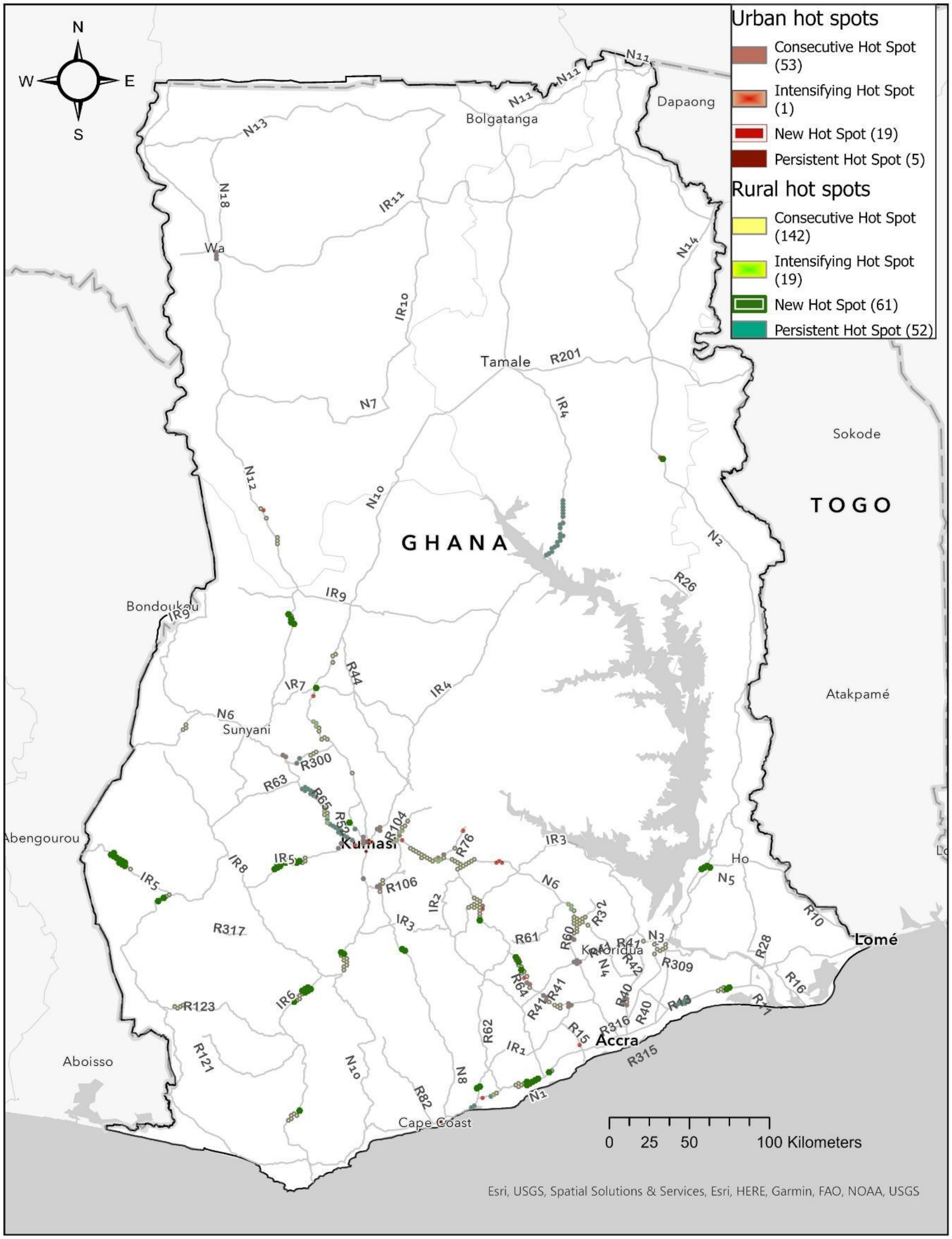
Emerging hot spot results: injury severity index (2005-2020)



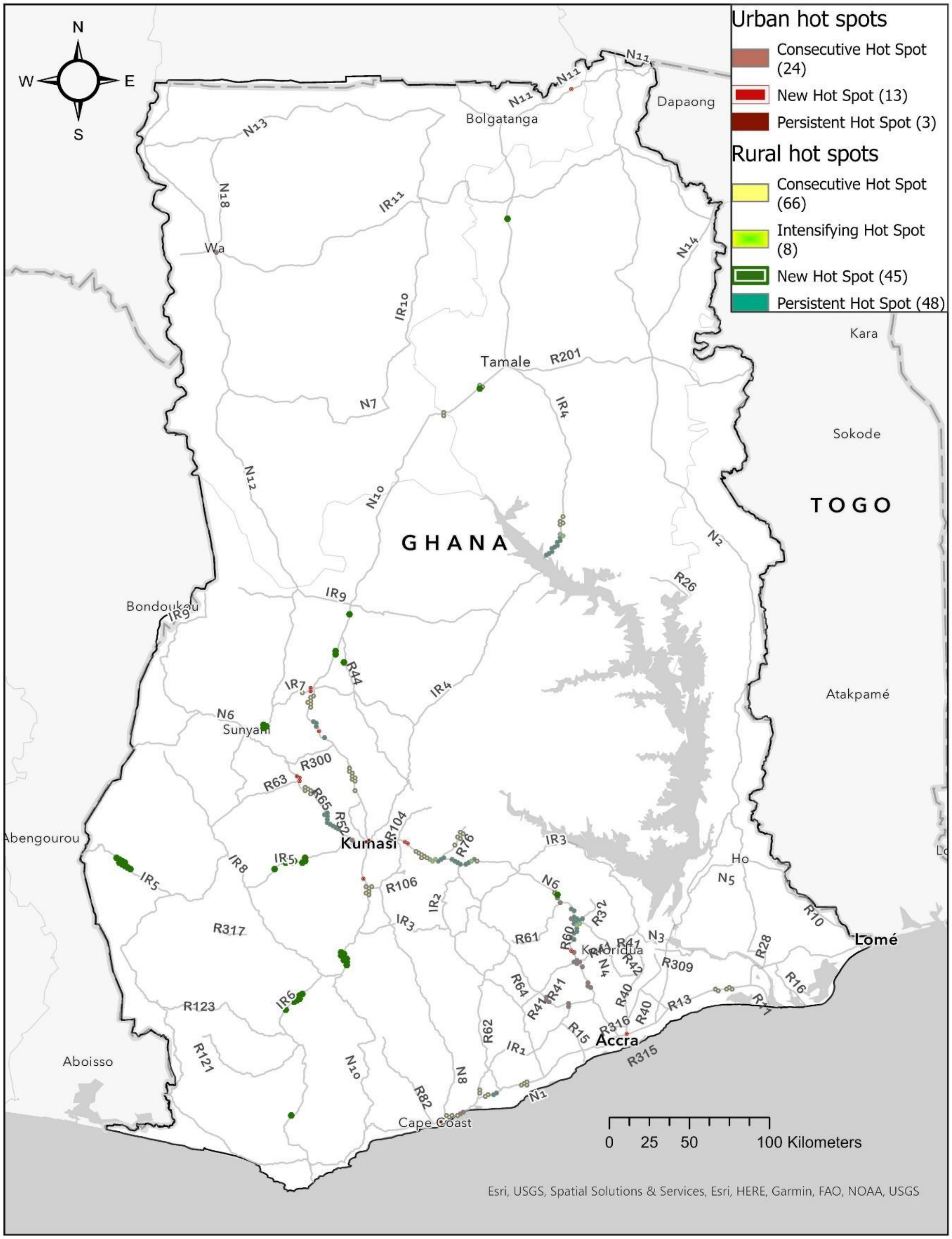
Emerging hot spot results – injury count, 2005 to 2020



Emerging hot spot results – severe injury count, 2005 to 2020



Emerging hot spot results – death count, 2005 to 2020



CHAPTER 4 APPENDIX

Partial proportional odds results for VRU and non-VRU

We present the odds ratios and 95% confidence intervals for each predictor, ordered from greatest to smallest odds ratio.

Vulnerable road users – partial proportional odds results

Predictor	OR, 95% CI – minor injury to severe injury and death	OR, 95% CI – – minor injury to severe injury	OR, 95% CI – minor injury to death
Elderly (reference: adult)	2.59 (2.25, 2.99)		
Head-on collision (reference: any non-head on collision type)	2.03 (1.88, 2.20)		
Rural area or village (reference: urban area)	1.81 (1.71, 1.91)		
Commercial heavy goods vehicle involved (reference, no commercial HGV involvement)	1.72 (1.49, 1.99)		
Night, no lights or lights off (reference: daytime)	1.54 (1.33, 1.77)		
Female (reference: male)		1.12 (1.05, 1.17)	1.33 (1.22, 1.46)
Child (<18 years) (reference: adult)	1.32 (1.22, 1.43)		
Time of day – night (reference: afternoon)	1.27 (1.12, 1.44)		
Commercial bus involved (reference: no bus involved)	1.18 (1.04, 1.32)		

Time of day – evening (reference: afternoon)	1.12 (1.01, 1.25)		
Inclement weather (reference: good, clear weather)	1.07 (0.98, 1.18)		
Median (reference: no median)	1.06 (0.97, 1.16)		
Car-involved collision (reference: no car)	1.03 (0.93, 1.13)		
Night, lights on (reference: daytime)	1.02 (0.92, 1.13)		
Curve, incline or any non-straight/flat road geometry (reference: straight and flat road)	1.02 (0.94, 1.12)		
Poor or overgrown shoulder (reference: good shoulder)	0.94 (0.88, 1.01)		
Three-vehicle collision (reference: single-vehicle collision)	0.91 (0.75, 1.10)		
Time of day – morning (reference: afternoon)	0.85 (0.79, 0.91)		
Segment (reference: intersection)	0.84 (0.78, 0.91)		
Two-vehicle collision (reference: single-vehicle collision)	0.83 (0.77, 0.89)		
No shoulder (reference: good shoulder)	0.82 (0.76, 0.87)		

Young driver-involved collision (reference: no young driver)	0.82 (0.76, 0.88)		
Powered two-wheeler involved collision (reference: no powered two-wheeler)	0.66 (0.60, 0.73)		
Powered three-wheeler involved collision (reference: no powered three-wheeler)	0.56 (0.49, 0.62)		

Non-vulnerable road user – partial proportional odds

Predictor	OR (95% CI)– minor injury to severe injury and death	OR (95% CI)– minor injury to severe injury	OR (95% CI)– minor injury to death
Head-on collision (reference: any non-head on collision type)	2.14 (2.01, 2.27)		
Passenger (reference: driver)	2.07 (1.96, 2.19)		
Night, no lights or lights off (reference: daytime)	1.36 (1.22, 1.51)		
Elderly (reference: adult)	1.32 (1.15, 1.53)		
Rural area or village (reference: urban area)	1.3 (1.24, 1.37)		
Commercial bus involved (reference: no bus involved)		1.16 (1.10, 1.22)	1.45 (1.33, 1.58)
Night, lights on (reference: daytime)	1.25 (1.15, 1.37)		
Female (reference: male)		1.11 (1.05, 1.18)	1.33 (1.22, 1.46)
Child (<18 years) (reference: adult)	1.20 (1.10, 1.32)		
Weekend (reference: weekday)	1.17 (1.11, 1.22)		
Curve, incline or any non-straight/flat road geometry (reference: straight and flat road)	1.08 (1.03, 1.14)		
Time of day – night (reference: afternoon)	1.07 (0.98, 1.17)		

Inclement weather (reference: good, clear weather)	1.06 (0.99, 1.14)		
Time of day – morning (reference: night)	0.98 (0.92, 1.03)		
Vehicle defects (reference: no vehicle defects)		0.81 (0.76, 0.85)	1.11 (1.02, 1.22)
Segment (reference: intersection)	0.91 (0.84, 0.98)		
Time of day – evening (reference: afternoon)	0.89 (0.81, 0.97)		
Poor or overgrown shoulder (reference: good shoulder)	0.87 (0.83, 0.93)		
Powered two-wheeler involved collision (reference: no powered two-wheeler)	0.86 (0.75, 0.98)		
No shoulder (reference: good shoulder)	0.77 (0.73, 0.82)		
Median (reference: no median)	0.76 (0.69, 0.83)		
Commercial heavy goods vehicle involved (reference, no commercial HGV involvement)		0.83 (0.77, 0.90)	0.67 (0.60, 0.76)
Two-vehicle collision (reference: single-vehicle collision)	0.70 (0.66, 0.75)		
Three-vehicle collision (reference: single-vehicle collision)	0.69 (0.62, 0.76)		

Vulnerable road user sub-groups descriptive statistics

In the following section, we present the detailed descriptive statistics for the VRU subgroups. We observe the most severe outcomes among pedestrians (28% were killed, and 53% were severely injured). Most victims are men across all groups. Adults make up the greatest population across all groups, although children are highly represented in the pedestrian category (29% of the injured population).

Outcome and road user related for VRU sub-groups: powered two-wheeler occupants, powered three-wheeler occupants, cyclists, and pedestrians

Variable	N	%	N	%	N	%	N	%
Outcome								
	Powered two-wheeler occupants (N=9,543)		**Powered three-wheeler (aboboyaa, pragya) occupants (N=1,596)**		**Cyclists (N=625)**		**Pedestrians (N=8,439)**	
Injury	9,543	100	1,596	100	625	100	8,439	100
Death	2,084	22	237	15	203	32	2,352	28
Severe injury	2,625	28	817	51	296	47	4,497	53
Minor injury	4,834	51	542	34	126	20	1,590	19
Road user factors								
Sex	8,439	100	1,596	100	625	100	8,439	100
Male	5,200	62	1,336	84	600	96	5,200	62
Female	3,239	38	260	16	25	4	3,239	38
Age categories	9,543		1,596	100	625	100	8,439	100
Child	497	5	190	12	104	17	2,447	29
Adult	8,914	93	1,383	87	481	77	5,383	64
Elderly	132	1	23	1	40	6	609	7
Road user type	9,543		1,596	100	625	100	8,439	100
Driver	7,098	74	852	53	597	96	0	0
Passenger	2,445	26	744	47	28	4	0	0
Pedestrian	0	0	0	0	0	0	8,439	100
Young driver	9,543	0	1596		625	100	8,439	100
Young driver involved	2,736	29	612	38	231	37	202	2

Pedestrians were most often hit by cars, (48%) followed by public transport vehicles. Very few vehicles had any defects across any of the groups. Most of the powered two-wheeler, powered three-wheeler, and bicycle collisions involved two vehicles.

Vehicle-related statistics for VRU sub-groups: powered two-wheeler occupants, powered three-wheeler occupants, cyclists, and pedestrians

Vehicle factors								
	Powered two-wheeler occupants (N=9,543)		**Powered three-wheeler (aboboyaa, pragya) occupants (N=1,596)**		**Cyclists (N=625)**		**Pedestrians (N=8,439)**	
Type of vehicle involved	10,48 9	110	327	21	142	23	8,564	101
Car	526	6	93	6	28	4	4,022	48
Powered two-wheeler	9,543	100	165	10	96	15	1,592	19
Powered three-wheeler (aboboyaa, Pragya)	156	2	1,596	100	3	0	214	3
Commercial, public transport	169	2	52	3	12	2	1,799	21
Commercial heavy goods	95	1	17	1	3	0	937	11
Number of vehicles	9,543		1,596	100	625	100	8,439	100
One vehicle	1,459	15	448	28	14	2	7,896	94
Two	7,834	82	1,099	69	590	94	442	5
Three or more	250	3	49	3	21	3	101	1
Vehicle defects	9,522		1,588	100	625	100	8,266	100
Any vehicle defects (e.g., brakes)	525	6	145	9	27	4	877	1061

Regarding environmental factors, most injuries occurred during good, clear weather, daytime, on straight/flat roads, and at intersections. Most injuries occurred on good, tarred roads with good shoulders. There was an equal distribution of injuries and deaths in urban and rural areas or villages.

Environmental statistics forVRU sub-groups: powered two-wheeler occupants, powered three-wheeler occupants, cyclists, and pedestrians

Environment factors								
	Powered two-wheeler occupants (N=9,543)		**Powered three-wheeler (aboboyaa, pragya) occupants (N=1,596)**		**Cyclists (N=625)**		**Pedestrians (N=8,439)**	
Weather	9,543		1,596	100	625	100	8,438	100
Good clear weather	8,113	85	1,448	91	521	83	7,169	85
Rain, fog, inclement conditions	1,430	15	148	9	104	17	1,269	15
Light conditions	9,541		1,596	100	625	100	8,439	100
Day time	6,164	65	1,130	71	411	66	5,469	65
Night, no lights, or night, lights off	867	9	93	6	63	10	571	7
Night lights on	2,510	26	373	23	151	24	2,399	28
Road description	9,542		1,596	100	625	100	8,437	100
Straight and flat	8,293	87	1406	88	562	90	7,607	90
Curve, incline, or other	1,249	13	190	12	63	10	830	10
Road surface type	9,542		1596	100	625	100	8,437	100
Tar, good	6,051	63	993	62	411	66	6,067	72
Tar, with few or many potholes	2,855	30	462	29	164	26	2,085	25
Gravel or earth	636	7	141	9	50	8	285	3
Shoulder condition	9,523		1596	100	624	100	8,429	100
Good	5,293	55	805	50	348	56	5,020	60
Poor or overgrown	2,173	23	362	23	129	21	1,522	18
No shoulder	2,076	22	429	27	147	24	1,887	22
Road separation			1588	100	622	100	8,416	100
Median	744	8	131	8	55	9	1,037	12
Surface condition	9,519	100	1587	100	625	100	8,417	100
Dry	94,33	99	1568	99	623	100	8,360	99

Wet/muddy	86	1	19	1	2	0	57	1
Location type			1596	100	624	100	8,439	100
Intersection	7,999	84	1397	88	544	87	7,482	89
Segment	1543	16	199	12	80	13	957	11
Traffic control	9535		1596	100	625	100	8,424	100
Any traffic control	1085	11	104	7	81	13	776	9
Type of area	9543	100	1596	100	625	100	8,439	100
Urban	4428	46	800	50	320	51	4,532	54
Rural or village	5115	54	796	50	305	49	3,907	46
Roadworks	9539	100	1596	100	625	100	8,434	100
At road works	23	0	1	0	0	0	35	100
Road width	4170	100	592	100	134	46	4,365	100
Less than 7.3 meters	2544	61	311	53	294	100	2,613	60

Most injuries and deaths occurred on weekends, in the afternoon, and while the vehicle was going ahead, compared to turning, overtaking or any non-going ahead movement. Head-on collisions comprised 33% of powered two-wheeler injuries and deaths, 27% of powered three-wheeler injuries and deaths, and 20% of cyclist injuries and deaths.

Other collision characteristics statistics for VRU sub-groups: powered two-wheeler occupants, powered three-wheeler occupants, cyclists, and pedestrians

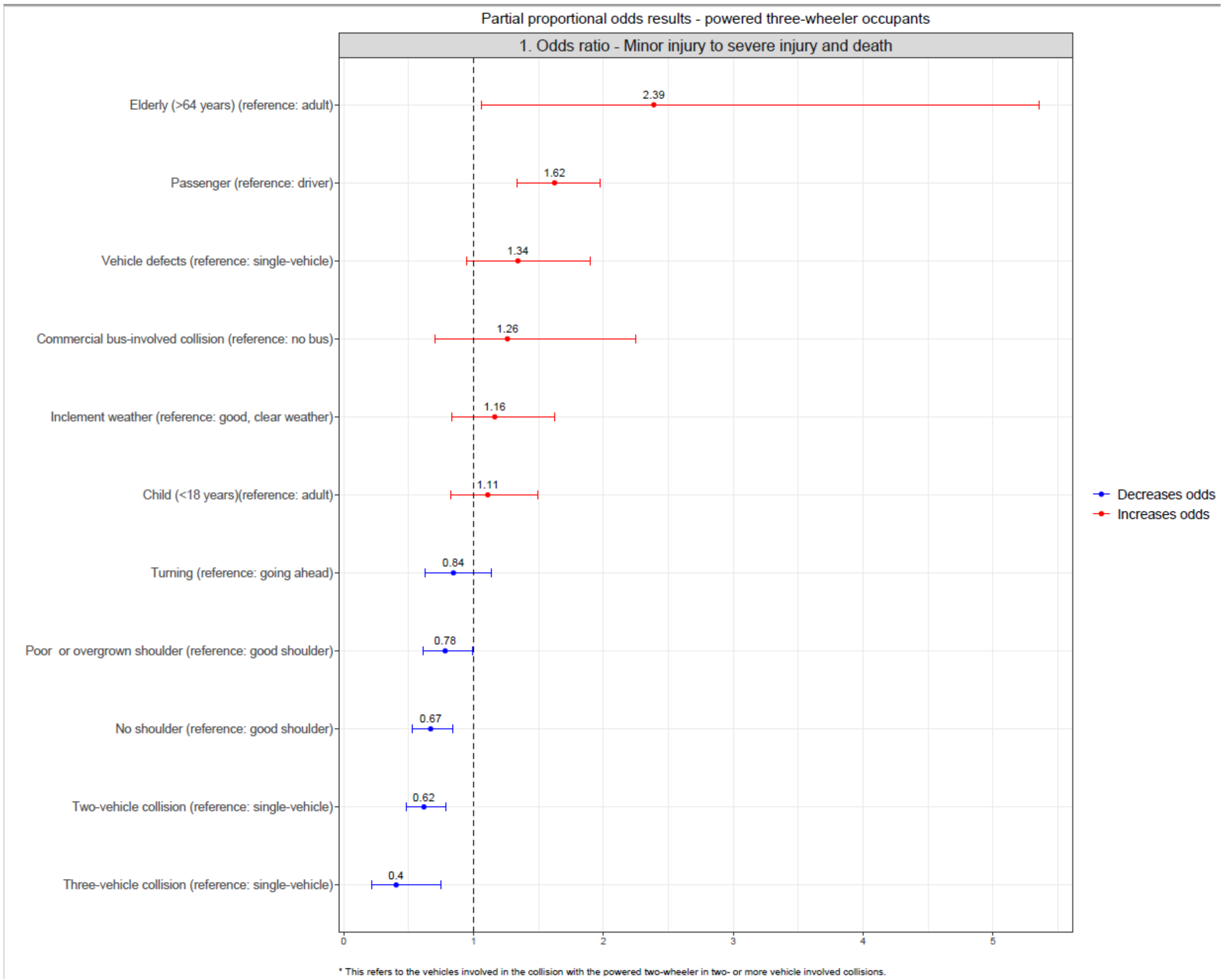
Other collision characteristics								
	Powered two-wheeler occupants (N=9,543)		**Powered three-wheeler (aboboyaa, pragya) occupants (N=1,596)**		**Cyclists (N=625)**		**Pedestrians (N=8,439)**	
Head-on collision status	9543	100	1596	100	625	100	8,439	100
Head on collision	3192	33	430	27	122	20	26	0
Vehicle maneuver	9534	100	1594	100	625	100	8,316	100
Going ahead	8531	89	1396	88	559	89	7,942	96
Turning or any non-going ahead action	1003	11	198	12	66	11	374	5

Day of the week	9543	100	1596	100	625	100	8,439	100
Weekend	2974	31	469	29	183	29	2,612	31
Time of day	9543	100	1596	100	625	100	8,439	100
Afternoon	3933	41	703	44	277	44	3,270	39
Evening	2498	26	356	22	161	26	2,206	26
Morning	2627	28	479	30	151	24	2,365	28
Night	485	5	58	4	46	6	598	7

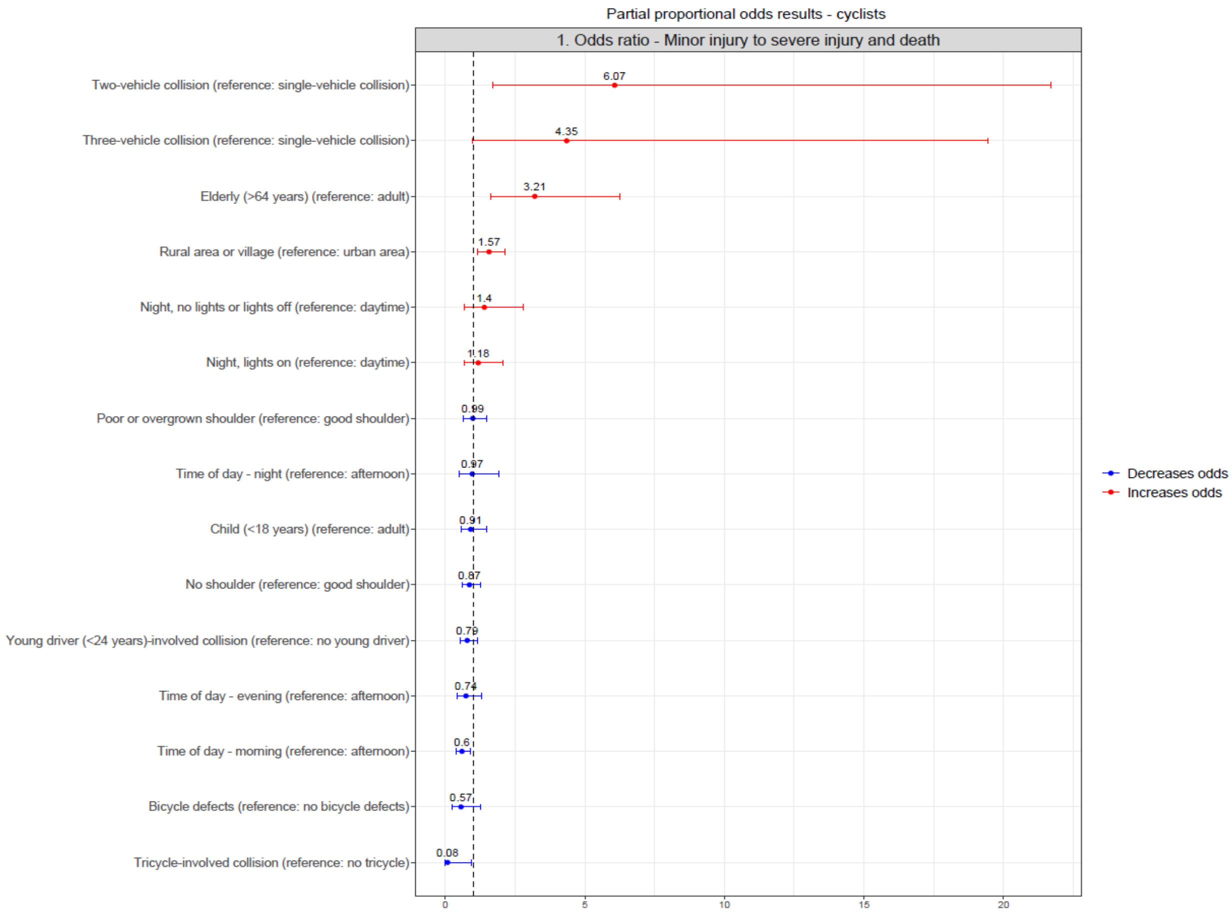
Proportional odds results by VRU subgroup

Partial proportional odds results - occupants of powered two-wheelers

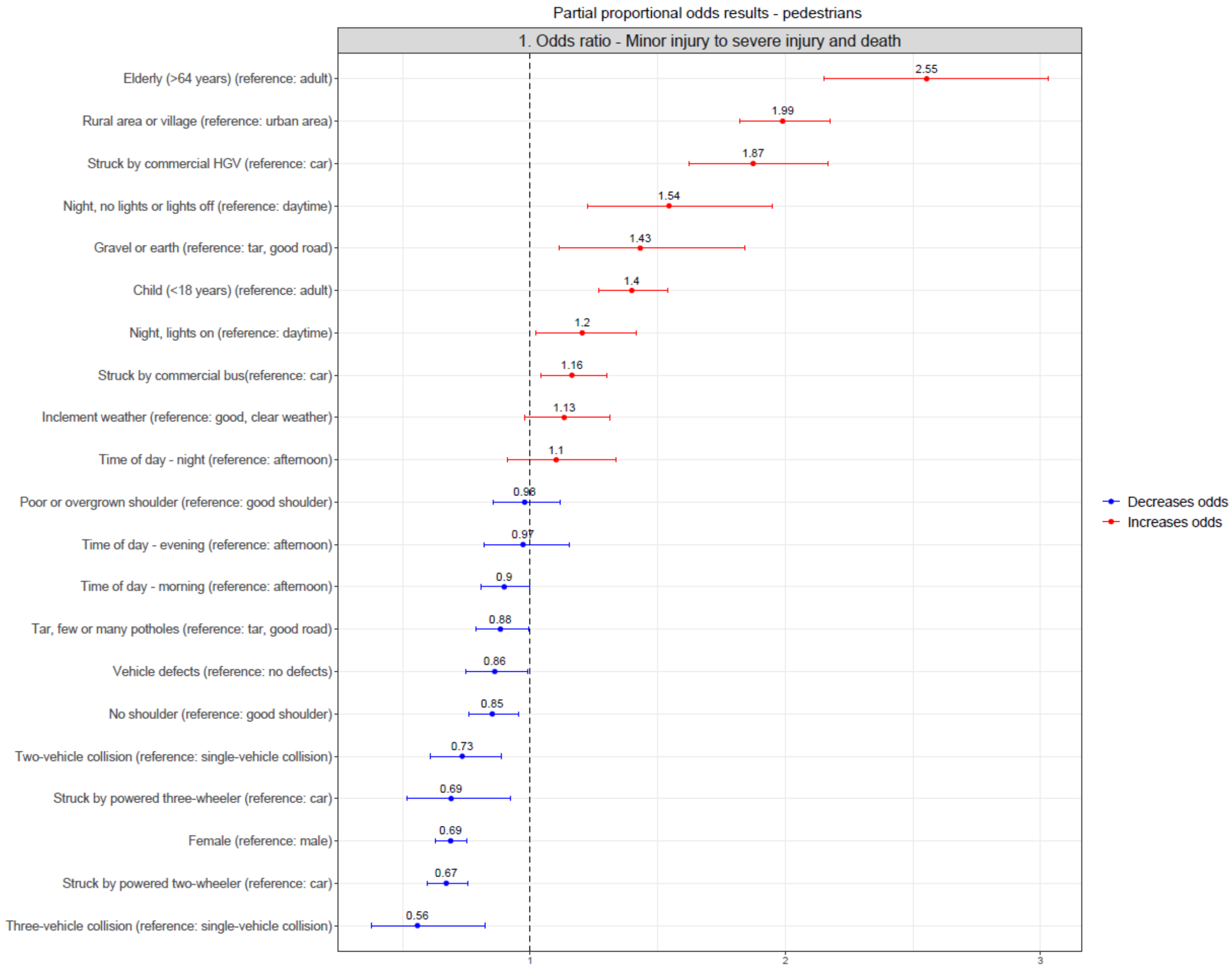
Partial proportional odds results - occupants of powered three-wheelers



Partial proportional odds results - cyclists



Partial proportional odds results - pedestrians



CHAPTER 5 APPENDIX

Road user in-depth interview guide

Introduction script

Good morning/afternoon. Can I have a few minutes of your time?

- My name is X, and I am from the Kwame Nkrumah University of Science and Technology (TECH). We have been doing research with a university in the US on the causes and possible ways to reduce accidents in Ghana.
- We will pay you 50 cedis for your time.
- We want to know your thoughts, opinions, and experiences about the causes of accidents and deaths so we can plan projects with the government.
- Your participation in this interview is voluntary, and you do not need to answer any questions that you do not want to.
- Please do not be shy. It won't take long – about 20 minutes.
- I would like to record our discussion so that we do not miss anything you say. Our discussion is completely confidential, we will not include your name with the recording, and we will not share your views with anyone outside of the team.
    - Is it okay to record our conversation?
- Now, we will go through a consent form together for you to sign.
- Can you please tell me your:
    - Age
    - Occupation
- Do you have any questions before we start?

Screening question

- How do you usually get around? How do you get to work? Do you use this road often?
- For example
    - walking, public transport (trotros), motorcycles, cars, taxis, trucks, riding a bike, tricycles (i.e., pragya)

General and pre-event phase questions

- How would you describe this area to others? Is this road busy?
- How big of a problem do you think accidents are here?
    - What do you think causes accidents here?
        - Road conditions (such as potholes, lack of sidewalks), abandoned/broken down vehicles, overspeeding, wrong overtaking, traffic
    - What do you think decreases the risk of an accident?
    - Are there some people who are more likely to get into an accident (for example, children, hawkers)?
    - Which age of children?
- Sometimes, personal stories can make road traffic problems more real. However, we know this can be sensitive.
- If you feel comfortable, can you share a story from an accident with me? Your own or someone else you know?
- Can you tell me of a story about a child getting in an accident on the roads, if you have one?
- Now, let's talk now about the police and their role.
- What do you think about the police's enforcement of laws now?
    - For example, speed, motorcycle helmets, unlicensed driving, broken vehicles
    - Do you think this affects collisions?
- If you had the power, what would you do to change the situation here?

Event questions

Once an accident does happen,

- What do you think causes people to die or get hurt, compared to just getting into a collision without getting hurt?
    - For example, what about the condition of the vehicle or trotro makes it more likely for a severe injury or death?
        - Like seat belts not working in cars/trotros, cars being old and not having airbags, position of seats, crowding
    - Generally, which people typically get injured or die in an accident?
        - For example, pedestrians, children, motorcyclists, bicyclists, and hawkers
        - Those without a helmet, those who do not use seat belts
    - What about the environment (such as the roads) makes it more likely for a severe injury or death?
        - For example, abandoned/broken down vehicles on the road, lack of sidewalks, potholes, traffic volume on roads
- What can be done to reduce the number of severe injuries and deaths here?

Post-event questions

- When people get into an accident or get hurt, what happens?
  - For example, do people call the police? Do people come help? Does an ambulance come? Tell me about what happened.
- When you call an ambulance, do they come?
  - How long would an ambulance take to arrive?
- Who gets an ambulance, and who doesn't?
  - For example, does it depend on if you are in an urban or rural area? Or the conditions of the road? Or if it's a major road and it causes congestion?
- If you had the power, what would you do to improve care after an accident?
  - For example, increasing number of ambulances, training people around in first aid

High-level questions – Intervention characteristics

- In your opinion, how much of a problem are accidents in Ghana?
- Does the government consider your views when they make decisions on road safety?
- What is the government currently doing to reduce accidents?
  - For example, speed bumps, enforcement by police, pedestrian bridges, education campaigns
  - Have you heard of those?
  - Have you seen those?
- Why do you think the government chooses these?
  - Are they considered better?
  - Are they cheaper? Do you think the government considers cost when they pick what to do?
- Where do ideas about road safety come from?
  - Do you think the government looks to other countries?
  - Or at research?
- We know other countries use enforcement cameras, where people get a fine immediately if they speed or run a red light – do you think we can do such a thing in Ghana?
- Why?
- What mark will you give the government on a scale of 1-10, with 10 being the best? Why that mark?

Closing question

Finally, our last question for you is:

- If you had the power, what would you do to reduce accidents, injuries, and deaths on the roads nationally?
    - o What would you do for pedestrians?
    - o What about motorcyclists?
    - o What about children?
- Is there anything else about collisions, injuries, or deaths on the roads that we haven't discussed today that you would like to tell me?
- Thank you for your time and participation in this important work.

VITA

Aldina Mesic has a decade of experience conducting rigorous public health research. She is interested in applying implementation science theories and geospatial epidemiological methods to routine data sources to assess the impact of public health interventions in low- and middle-income countries. Aldina holds a Master in Public Health in Monitoring and Evaluation and Maternal and Child Health from Boston University and a Bachelor of Science in Biology from Northeastern University. Aldina has worked on research studies focused on injuries (e.g., road traffic, burns), gun violence, intimate partner violence, substance use, maternal health, and HIV in Ghana, Zambia, Rwanda, Vietnam, Bangladesh, and the United States.