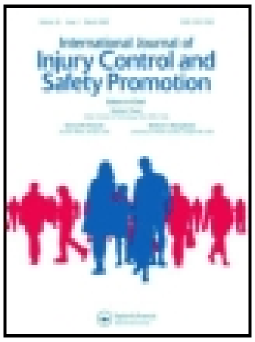

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RESEARCH ARTICLE

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Investigation of road infrastructure and traffic density attributes at high-risk locations for motorcycle-related injuries using multiple correspondence and cluster analysis in urban Tanzania

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ABSTRACT

Rapid growth in use of motorcycles combined with limited road infrastructures has increased the burden of road traffic crashes and injuries in low-and middle-income countries. The aim of this study was to assess whether high-risk locations for motorcycle-related injuries identified from police crash data registers for the period 2016 to 2017 share similar road infrastructure and traffic density attributes in Dar es Salaam city. Analysis was performed using multiple correspondence and hierarchical cluster analysis. Three distinct clusters for motorcycle injury hotspots were identified. Clusters 1 and 2 were associated with more fatal and severe injuries and were characterized by overrepresentation of trunk roads, unseparated two-way roads, mixture of road users and commercial and residential areas compared to Cluster 3. Cluster3 was associated with less severe injuries compared to clusters 1 and 2 ($p < 0.001$). Cluster 3 was characterized by overrepresentation of feeder/street roads, separated two-way roads and presence of traffic control measures. The clusters of hotspots differed by road infrastructure and traffic density attributes. Clusters 1 and 2 were characterized by more dangerous road environments, while cluster 3 was characterized by road environments with less severe outcomes. These findings can assist in prioritizing preventive strategies for motorcycle- related injuries.

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Crash; injuries; road infrastructure; motorcycle; hotspots; cluster analysis

Introduction

Tanzania, like many other low- and middle-income countries (LMICs) is affected by the burden of road traffic injuries (RTI). The number of road traffic deaths per 100,000 population is estimated to be 29 per 100,000 population which is one of the highest in the African region (WHO, 2018). The rapid growth in the burden of RTI is contributed by increasing economic trends which enable many people to own or use motorcycles as an alternative mode of transportation for goods and services within the existing, limited road infrastructure regarding space and safety for motorcyclists (Nyachieo, 2015; Wanume, 2019). An analysis of data from six public hospitals in Tanzania revealed that motorcycle crashes accounted for 53.4% of all road traffic injuries (Boniface *et al.*, 2016). In addition, the number of motorcycle-related deaths rose from 10% in 2008 to 24% in 2015. Motorcycle-related crashes and injuries are not randomly distributed over space and time, they are concentrated more on certain sections of the road network (Plug *et al.*, 2011; Shiode, 2008; Steenberghen *et al.*, 2004). Previous studies have shown that trunk roads/highways and collector roads (Harnen, 2006), T-intersections, horizontal curve (Abdul Manan *et al.*, 2018; Salum *et al.*, 2019) and higher traffic volume locations in urban areas (Machsus *et al.*, 2014)are associated with higher risks of motorcycle crashes and injuries. Thus, areas with more than averagenumber of crashes and injuries can be defined as hotspots or black spots (Erdogan *et al.*, 2008). To build effective crash prevention measures specifically for motorcycles, there is a need to deepen the understanding of relationships between different road infrastructure and traffic density attributes, and their influences on the concentration of motorcycle crashes and injuries on road networks. Studies have suggested that road infrastructure including geometric way design and road layout play an important role in determining risk of road traffic crashes (Ahmed, 2013; Polus *et al.*, 2005).

Road infrastructures have proved to have larger impact on crash and injury risk among motorcyclists than on car drivers(ACEM, 2004; Saleh *et al.*, 2010; Van Elslande, 2013; Xiong *et al.*, 2016). Motorcyclists are more sensitive to poor road conditions and they need more balance on the road than car drivers (Hurt & DuPont, 1977; Mannering & Grodsky, 1995). Many low and middle-income countries suffer from poor road environment and have a mixture of different types of road users compared to high-income countries (Mohan, 2002). Despite the rapid increase in the use

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of motorcycles as means of transportation of goods and services in LMIC (Solagberu, 2006), there are limited studies that have examined the combined effect of road infrastructures and traffic density attributes on the risk of motorcycle crashes and injuries. Therefore, the aim of this study was to assess whether high-risk locations (so-called hotspots) for motorcycle-related injuries share similar road infrastructure and traffic density characteristics in the city of Dar es Salaam, Tanzania. A deeper understanding of this may help to develop and prioritise prevention strategies for motorcycle-related crashes and injuries.

Methods

Study design

This cross-sectional study was based on police-reported data involving motorcycle-related crashes that occurred between 2015 and 2016. Collected data were used to determine the motorcycle-related injury hotspots. An observation took place at each identified hotspot to assess road infrastructure characteristics and traffic density.

Study setting

The study was conducted in Dar es Salaam. It is the largest city in East Africa and third fastest-growing city on the continent and is located in the United Republic of Tanzania on the coast of the Indian Ocean. Dar es Salaam lies at 5.17°, 5.33°S and covers an area of 1,590 square kilometres. The total population in the city is estimated to be 5.2 million inhabitants, of which 25% are young men between 15 and 35 years of age (NBS, 2018). Dar es Salaam is the primary economic hub of Tanzania containing the main gateways, including the main airport and port that serve other mainland regions as well as neighbouring countries. Motorcycles are one of the most common modes of transportation used for both private transport and as commercial motorcycle taxis service in the city of Dar es Salaam. One reason is motorcyclists' ability to move easily in traffic congestions. The number of motorcycles has increased exponentially and the approximate number by 2016 was 302,169 (Salum *et al.*, 2019). A motorcycle helmet laws was implemented in Tanzania in 2010 for both riders and passengers. According to a survey conducted in the city of Dar es Salaam, the prevalence of helmet use was 82.1% among motorcycle riders and 22.5% among motorcycle passengers (Kauky *et al.*, 2015).

Data collection

Motorcycle-related crash and injury data were extracted from the regional police registers and case files. The case files of each identified motorcycle crash were reviewed and details information on crashes and their consequences were extracted. Variables extracted included information on the location of the crash, date and time of the crash, day of the week, as well as information about the injured persons, such as age, type of road user, and injuries sustained. Death was defined as a death that was recorded on-site or within 30 days after the crash (Bachani *et al.*, 2012). Fractures, unconsciousness, head, chest, and wrist injuries or injuries that make the victim unable to work for more than seven days were classified as severe injuries (Bos, 2016) while minor bruises, scratches, dislocation, and unspecified injuries were classified as minor injuries (Reurings & Stipdonk, 2011).We assumed that minor injuries were more likely to be reported as unspecified than severe and fatal outcomes, therefore all unspecified injuries were classified as minor injuries. About 6% of the injuries were unspecified in the case files.

Sample characteristics

Out of 8,060 road traffic crashes, 2,267 (28.1%) of crashes were involved motorcycles. We extracted information of 1,858 (82.0%) motorcycle crashes with 2,588 injured persons, and 409 (18.0%) crashes with non-injured persons from the police case files. Most of the crashes were involved minor injuries (51.3%), followed by severe injuries (35.1%) and fatal injuries (13.6%). Most of the crashes were involved collisions between motorcycles and cars (60.7%), motorcycles and pedestrians (25.2%), and motorcycles with other motorcycles (9.7%). More than half (52.0%) of the crashes occurred at intersections and involved side-by-side collisions (66.8%), head-on collisions (15.5%), or rear-end collisions (14.7%). Over 50.0% of the injured persons involved were motorcycle drivers, followed by passengers (25.1%) and pedestrians (22.2%)

Hotspot identification

To determine the motorcycle-related injury hotspots, we extracted an exact location of a crash or proximity location coordinates (x, y) from Google Earth using addresses provided for each location. Locations that could not be identified through Google Earth were physically visited, and then the coordinates were collected by Android phones. All the points collected were downloaded and transferred into ArcGIS software 10.2 and saved as shapefiles (.shp). The points were projected into the Universal Transverse Mercator and overlaid on the roads network in Dar es Salaam using ArcGIS software. Points that appeared outside the city boundary were verified using Google Earth and thereafter updated in the dataset. Motorcycle-related injury hotspots were determined using the Kernel Density Estimation method (KDE). The KDE is a non-parametric tool that is used to estimate the spread of the risk of the occurrences of events within the predefined radius or bandwidth. KDE involves overlaying continuous surfaces on each point and evaluating the distances from the point to the reference based on a mathematical function. All the values were summed up to estimate the density distribution for the crashes. The KDE was estimated using the following formula given by (Fotheringham *et al.*, 2000):

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^{n} K\left\{\frac{dis}{h}\right\}$$

Where *f(x,y)* is the estimated density at the location *(x,y)*, h is the radius (bandwidth), n is the number of observations, *dis* is the distance between point i and the location *(x, y)*, K is the kernel smoothing function. To account for the impact associated with crash at the given location *(x, y)*, the KDE was weighted by Severity Index SI (Truong & Somenahalli, 2011). Each crash was assigned weight according to its impact on injury severity whereby fatal injury event was assigned a higher weight value as compared to severe and minor injuries. The SI at the location *(x, y)* was computed using the formula given by (Truong & Somenahalli, 2011):

$$SI_i = 5 * F + 3 * S + 1 * M$$

Where;

F = Total number of deaths at location *(x, y)*

S = Total number of severe injuries at location *(x, y)*

M = Total number of minor injuries or property damage at location (x,y)

According to our calculation, the search radii (bandwidth) of 500 metres and grind cells size of 50 m by 50 m were used to identify the hotspots. The KDE produced quantitative measure presenting a magnitude reflecting potential risk level to crash occurrence within predefined bandwidth. Thus, the road section with a higher value indicates a higher chance of crashes than that with low value. In this study, the significant hotspots were defined as those locations with more than 2-standard deviation of the probability density. Hotspot analysis was performed using ArcGIS software (Harnen, 2011; Truong & Somenahalli, 2011).To validate the model the Spearman correlation was used to assess the degree of associations between total number of injuries, number of minor and severe injuries, fatalities, number of vehicles involved in collisions, and type of collisions for crashes within the hotspots as well as for the entire sample of motorcycle-related crashes recorded within the entire study area. The Spearman correlation coefficient was above 0.6 both for crashes within the hotspots and the entire sample of crashes indicating the best fit of the model on data, which were used for identification of motorcycle-related injury hotspots.

Figure 1 presents the distribution of hotspots of motorcycle-related injuries in the city using the Kernal Density Estimation.

The Figure shows that most of the hotspots were located at intersections, on trunk roads and collector roads and within city centre.

Road infrastructure and traffic density attributes at hotspots

Data on road infrastructure and traffic density were collected at each hotspot using road safety audit checklists adapted from other studies (Abdul Manan *et al.*, 2018; De Silva *et al.*, 2018; Waldon *et al.*, 2018). The checklists were modified to fit our settings. Variables collected including road classification (trunk, collectors and feeder roads). According to Tanzania road classification, trunk roads include major/arterial roads which are characterized by higher speed and a mixture of buses, lorries and cars. Collector roads are the type of roads which collect traffic from other streets and discharge them onto other collector or trunk roads while feeder roads are local roads which primarily used to provide access to the traffic originating from the properties and discharge them onto collector (Tanzania Works, 2011).Other variables collected include,

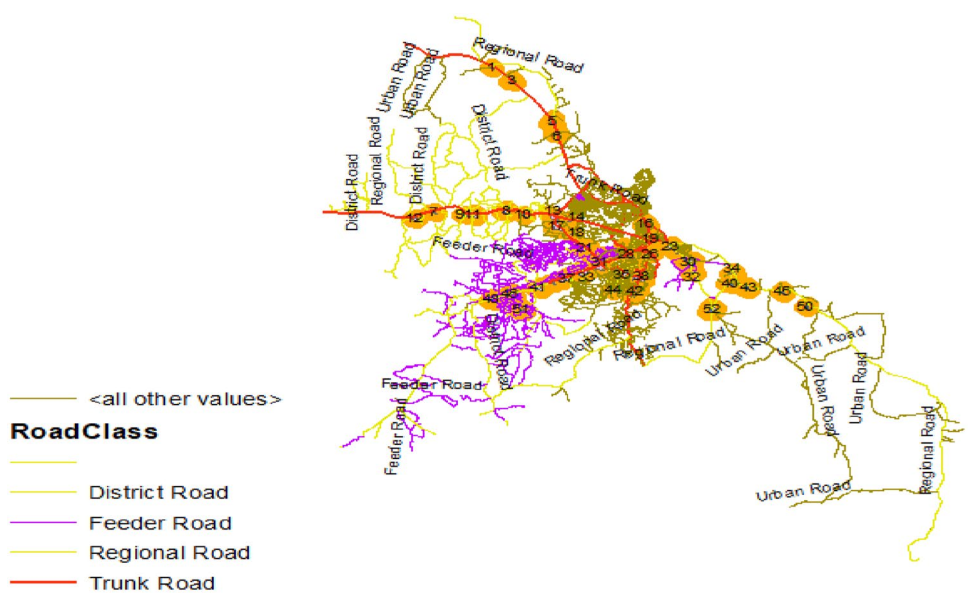

Figure 1. Distribution of motorcycle-related injury hotspots identified using the kernel density estimator in Dar es Salaam.

road layout (smooth and flat, horizontal, vertical curve), narrowing road (yes/no), road marking (solid line marking, single line marking, no-line marking), road shoulders (paved/unpaved), road type (one-way with one lane, two-ways with two lanes separated, two-ways with two lanes unseparated), quality of road surfaces (rough, smooth, defective), types of intersections (no-intersection, T-intersection, X-intersection, Y-intersection), presence of traffic lights (yes/no), speed bumps (yes/no), pedestrian crossing (yes/no), adjacent land use (residential, commercial, mix of a commercial and residential, bus stop) and traffic density. A manual count for the number of cars, pedestrians, cyclists, motorcycles, busses/lorries was carried out to compute the traffic density within identified motorcycle-related injury hotspots per five-minute intervals (Abdul Manan *et al.*, 2018). The observation and count were carried out from 9:00 am to 3:00 pm on three days in week (Tuesday, Wednesday and Thursday). It is believed that, there are no major differences in traffic intensity during these times and days that could be confounded by high traffic volumes during the rushing/peak-hours, the first day of the week (Monday) and during the weekends (Friday/Sunday). The estimated average traffic density per five-minute intervals for different road users was categorized into tertiles, the low tertile representing low traffic density, the middle tertile- moderate and the high tertile-high traffic density.

Assessment of crash characteristics

Data on crash characteristics recorded at the high-risk locations were used to describe the patterns of the crashes that form the clusters. Days of the week were categorized into three groups (Monday, Tuesday to Thursday, and Friday to Sunday). This categorization was based on traffic patterns and designed to eliminate confounding variables surrounding the different traffic volumes associated with different days of the week. Monday is the busiest day of the week; therefore, it is always linked to a high traffic density. Friday to Sunday was considered as the weekend, and most of the social events usually take place during weekends. Time was categorized as daytime (6:00 am – 6:59 pm) and night-time (7:00 pm – 5:59 am) (Zhang & Hassan, 2019). The collisions were classified in relation to the object involved such as collision between motorcycle with cars, motorcycle with other motorcycle, motorcycle with pedestrians and motorcycles with other objects (bicycles/tricycles). The collision types (side-way impact, head-on, and rear-end collision) were compared across clusters.

Multiple correspondence and hierarchical agglomerative clustering analysis

Multiple Correspondence Analysis (MCA) was used to assess the interrelationship between set of road infrastructure and traffic density categorical variables and reduce them into a system of quantitative data in low dimensions (Cattell, 2012; Greenacre, 1991). In principle, the MCA dichotomized each category of the different road infrastructure and traffic density variables and created a set of new variables that were used to summarise the data. The MCA produces the results in the form of correlation coefficient matrixes. The correlation analysis indicates the amount at which each variable and its corresponding categories contributed to the formation of dimension/component. We used the Kaiser Meir Criteria to assess and decide on the number of dimensions to be retained to summarize the data, where the rule of thumb should be to retain the dimensions that contribute to the maximum variations (Greenacre, 1991).Hierarchical Agglomerative Clustering (HAC) algorithm used quantitative data (dimensions/components) generated by MCA (as input) to uncover the patterns of motorcycle injury hotspots based on the road infrastructure and traffic density attributes. The HAC is an ascendant method that classifies the objects into homogeneous groups without predefined criteria on the number of clusters based on dissimilarities or distance between pairs of observations.

Statistical analyses

Descriptive statistics including frequencies and proportions were used to summarize data. Chi-square tests or Fisher exact tests were used to assess the associations between crash characteristics and clusters. The P-value was considered significant at $p < 0.05$. Analyses of the data were performed using FactoMineR- R-package (Lê *et al.*, 2008) and Stata software.

Ethical approval

The study was granted ethical approval by the Research and Ethics Committee of the Muhimbili University of Health and Allied Science with reference number (2017-07-21/AEC/Vol.XII/87). Permits to retrieve data from the police register in the traffic stations were obtained from the traffic regional offices of Ilala, Kinondoni, and Temeke.

Results

Hotspot characteristics

A total of 46 hotspots for motorcycles, involving 727 motorcycle-related crashes ranging from 6 to 56 events/hotspots, were identified. The majority (47.8%) of the hotspots were located on trunk roads, followed by collector roads (28.3%), and feeder roads (23.9%). High proportions (43.5%) of the hotspots were characterized by straight and flat roads and were located at T-intersections (52.2%). Over half of the hotspots (54.3%) were located on one-way roads with two lanes, as well as roads with single-lane line marking (62.2%). Almost 60% of the hotspots had no traffic control. A majority (63.0%) of hotspots were located within residential and commercial areas. The hotspots varied in terms of traffic density, from areas with few cars, buses, and pedestrians to areas with dense traffic (Table 1).

Table 1a. Road characteristics and traffic densities in motorcycle injury hotspots (n = 46).

Characteristics	Frequencies, (%)
Road class	
Collector	13(28.3)
Feeder	11(23.9)
Trunk	22(47.8)
Road type	
One-way with one lane	6(13.0)
Two-ways with two lanes (unseparated)	25(54.3)
Two-ways with two separated lanes	4(8.7)
Two-ways with two separated roads (two lanes each)	11(23.9)
Road layout	
Straight and flat	20(43.5)
Horizontal curve	14(30.4)
Vertical curve	12(26.1)
Intersection type	
No intersection	10(21.7)
T-intersection	24(52.2)
X-Intersection	8(17.4)
Y-intersection	4(8.7)
Narrowing road	
No	17(37.0)
Yes	29(63.0)
Road lane line marking	
Solid lane line	6(11.1)
Single lane line	28(62.2)
No line	12(26.7)
Presence of traffic light	
No	28(60.9)
Yes	18(39.1)
Speed bump	
No	27(58.7)
Yes	19(41.3)
Zebra crossing	
No	9(19.6)
Yes	37(80.4)
Road shoulder	
Unpaved	23(50.0)
Paved	23(50.0)
Drainage facility	
No	18(39.1)
Yes	28(60.9)
Road surface quality	
Rough	3(6.5)
Smooth	29(63.1)
Defective	14(30.4)

Table 1b. Characteristics of road infrastructure variables and traffic densities within motorcycle injury hotspots (Continued).

Characteristics	Frequencies, (%)
Adjacent land use	
Only commercial	3 (6.5)
Only residential	4 (8.7)
A mix of residential and commercial	29 (63.0)
Bus stop	10 (21.7)
Traffic density, count/5 minutes	
Number of cars	
3-35	17 (37.0)
36-60	15 (32.6)
61-101	14 (30.4)
Number of motorcycles	
1 – 21 motorcycles	12 (26.1)
22 – 45 motorcycles	14 (30.4)
46 – 105 motorcycles	15 (32.6)
Number of buses/lorries	
No-bus/lorry	16 (34.8)
1-28 buses/lorries	15 (32.6)
29-51 buses/lorries	15 (32.6)
Number of pedestrians	
1-20	16 (34.8)
21-50	17 (37)
51-130	13 (28.3)

Table 2a. Classification of motorcycle injury hotspots based on the homogenous group according to the road infrastructure characteristics and traffic density.

Variables	Cluster 1 (n = 15), n (%)	Cluster 2 (n = 19), n (%)	Cluster 3 (n = 12), n (%)	Total (n = 46), n (%)
Road class				
Collector	**9(60.0**)	3(15.8)	1(8.3)	13(28.3)
Feeder	5(33.3)	0(0)	**6(50.0)**	11(23.9)
Trunk	1(6.7)	**16(84.2)**	5(42.7)	22(47.8)
Road type				
One-way with one lane	2(13.3)	2(10.5)	3(25.0)	7(15.2)
Two-way with two lanes(unseparated)	**10(66.7)**	**13(68.4)**	2(16.7)	25(54.3)
Two-way with two separated lanes	3(20.0)	4(21.1)	**7(58.3)**	14(30.4)
Road design				
Straight and flat	5(31.3)	3(15.9)	**11(78.6)**	19(43.5)
Horizontal curve	**10(62.5)**	5(26.4)	1(7.1)	16(34.8)
Vertical curve	1(6.3)	**11(57.9)**	2(14.3)	11(23.9)
Intersection type				
No intersection	**6(40.0)**	2(10.5)	2(16.7)	10(21.7)
T-intersection	5(33.3)	**16(84.2)**	3(25.0)	24(52.2)
X-intersection	0(0)	1(5.3)	**7(58.3)**	8(17.4)
Y-intersection	4(26.7)	0(0)	0(0)	4(8.7)
Narrowing road				
No	5(34.0)	7(36.8)	**10(83.3)**	17(37)
Yes	**10(66)**	12(63.2)	2(16.7)	29(63)
Road shoulder				
Paved	2(13.3)	**8(42.1)**	**5(41.7)**	15(32.6)
Unpaved	**13(86.7**)	11 (57.9)	7(58.3)	31(67.4)
Land use type				
Residential only	2(13.3)	0(0)	2(16.7)	4(8.7)
Commercial only	0(0)	0(0)	3(25.0)	3(6.5)
Residential and commercial	**11(73.4)**	**17(89.5)**	1(8.3)	29(63)
Bus stop	2(13.3)	2(10.5)	6(50.0)	10(21.7)
Presence of drainage facility				
No	**9(60.0)**	9(47.4)	3(25.0)	21(45.7)
Yes	6(40.0)	10(52.6)	**9(75.0)**	25(54.3)
Road surface quality				
Rough	2(13.2)	0(0)	1(8.3)	3(6.5)
Smooth	5(33.5)	**14(73.7)**	**10(83.5)**	29(63.0)
Defective	**8(53.3)**	5(26.3)	1(8.3)	14(30.4)

Multiple correspondence analyses

Overall, the first two dimensions of the MCA accounted for 38.4% of the total variations. The first and second dimensions contributed 25.0% and 13.4% of total variation and their corresponding eigenvalues were 0.28 and 0.15, respectively. Two dimensions contributed a maximum variation was extracted and used with HAC to identify and to explore characteristics associated with clusters of motorcycle injury hotspots as shown in Figure 2.

Figure 3 presents the perceptual map of the correlations of different categories of corresponding road infrastructure and traffic density variables investigated. Location of the category on the factor perceptual map indicates that the categories located closer to one another they are highly correlated than those located at distant. The first quadrant located at the top left corner of the factor perceptual map indicates that feeder roads, absence of pedestrian signs, speed bumps, and numbers of cars that were strongly related. The second quadrant at the top-right of map

Table 2b. Classification of motorcycle injury hotspots based on the homogenous group according to the road infrastructure characteristics and traffic density (Continued).

Variables	Cluster 1 (n = 15), n (%)	Cluster 2 (n = 19), n (%)	Cluster 3 (n = 12), n (%)	**Total (n = 46), n(%)**
Road marking				
Solid line marking	1 (6.7)	1 (5.3)	3 (25.0)	5 (10.9)
Single line marking	7 (46.7)	**14 (73.7**)	**8 (66.7**)	29 (63.0)
No line marking	**7 (46.7**)	4 (21.0)	1 (8.3)	12 (26.1)
Presence of traffic light				
No	9 (60.0)	10 (52.6)	3 (25.0)	28 (60.9)
Yes	**6 (40.0)**	**9 (47.4)**	**9 (75.0)**	18 (39.1)
Presence of speed bump				
No	**13 (86.7**)	**11 (57.9)**	3 (25.0)	27 (58.7)
Yes	2 (13.3)	8 (42.1)	**9 (75.0)**	19 (41.3)
Pedestrian crossing				
No	**6 (40.0)**	**9 (47.4)**	2 (16.7)	17 (37.0)
Yes	9 (60.0)	10 (52.6)	**10 (83.3)**	29 (63.0)
Number of cars				
3 – 35 cars	**8 (55.3)**	2 (10.5)	**5 (41.7)**	15 (32.6)
36 – 60 cars	**5 (33.3)**	8 (42.1)	3 (25.0)	16 (34.8)
61 - 101cars	2 (13.3)	**9 (47.4)**	**4 (33.3)**	15 (32.6)
Number of motorcycles				
1-21 motorcycles	**6 (40.0)**	3 (15.8)	3 (25.0)	12 (26.1)
22 – 45 motorcycles	2 (13.3)	**7 (36.8)**	**4 (33.3)**	13 (28.3)
46 – 105 motorcycles	**7 (46.7)**	**9 (47.4)**	5 (41.7)	21 (45.6)
Number of busses/ lorries				
No bus/lorry	**8 (53.0)**	2 (10.5)	**10 (83.3)**	20 (43.5)
7-28 busses/ lorries	4 (26.7)	**7 (58.3)**	1 (8.3)	12 (26.8)
29-51 busses/ lorries	3 (20.0)	**14 (73.7)**	1 (8.3)	14 (30.4)
Number of pedestrians				
<20	**10 (66.7)**	5 (26.3)	1 (8.3)	16 (34.8)
21-50	2 (13.3)	**10 (52.6)**	**5 (41.7)**	17 (37.0)
51-130	3 (20.0)	4 (21.1)	**6 (50.0)**	13 (28.2)

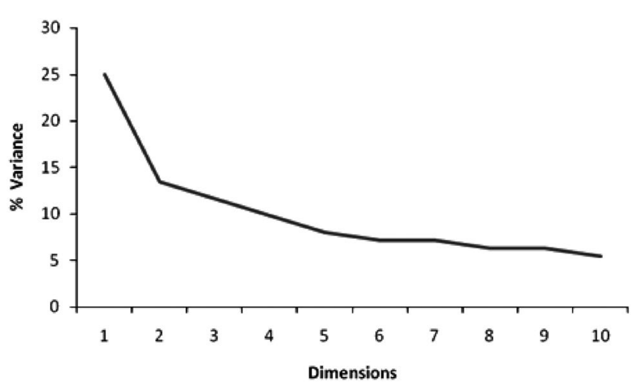

Figure 2. Scree plot of top ten dimensions of Multiple Correspondence Analysis.

indicates the presence of drainage facilities, straight and flat roads and smoothness of road surface were strongly related. The third quadrant, located at the bottom-right of the factor map indicated the relationship between trunk roads, presence of speed bumps, and the number of cars. The fourth quadrant of the factor map (bottom-left) showed two-way traffic with a lane moving in the opposite direction, narrowing roads, absence of traffic lights, number of pedestrians, and areas located within residential and commercial were correlated. Also, an interpretation of perceptual map demonstrates that categories located within the same quadrant imply they are more related in comparison to the features located at different quadrants.

Clusters of motorcycle injury hotspots

Table 2 shows the distribution of road characteristics and traffic density within clusters of motorcycle injury hotspots. Three distinct clusters consisting of (32.6%, n = 15), (41.3%, n = 19) and (26.1%, n = 12) motorcycle injury hotspots locations were identified.

Cluster 1 (n = 15 hotspots)

The majority of the hotspots in the cluster were characterized by overrepresentations of unpaved road shoulders (86.7%) and the absence of speed bumps (86.6%) compared to other clusters. Nearly three-quarters of the hotspots in cluster 1 were associated with a high proportion of locations with a mix of residential and commercial areas. Further, results showed that almost 60.0% of the hotspots in cluster 1 were located on the collector roads, unseparated two-way roads within horizontal curves and at the road sections with drainage facilities on both sides of the roads. Half of the hotspots in cluster 1 were also characterized by an overrepresentation of defective road surfaces. Additionally, cluster 1 was associated with the hotspots characterized by overrepresentation of a mixture of higher number of cars and pedestrians compared to cluster 3 (Table 2).

Cluster 2 (n = 19 hotspots)

Cluster 2 was characterized by an overrepresentation of the hotspots located within residential and commercial areas (89.5%), on trunk roads and T-intersections (84.2%) compared to other clusters. Almost (70.0%) of the hotspots in cluster 2 were characterized by unseparated two-way roads, single-lane line-markings and smooth road surfaces compared to other clusters. On the other hand, nearly half of the hotspots in cluster 2 lacked pedestrian zebra crossings and traffic light facilities, respectively. Almost (57.0%) of the hotspots in cluster 2 had overrepresentation of vertical curves compared to other clusters compared to other clusters. Furthermore, cluster 2 was also characterized by overrepresentation of hotspots with a mixture of heavy and cars as well as different road users compared to the other clusters (see Table 2).

Cluster 3 (n = 12 hotspots)

The majority (83.3%) of the hotspots in cluster 3 were characterized by an overrepresentation of the presence of

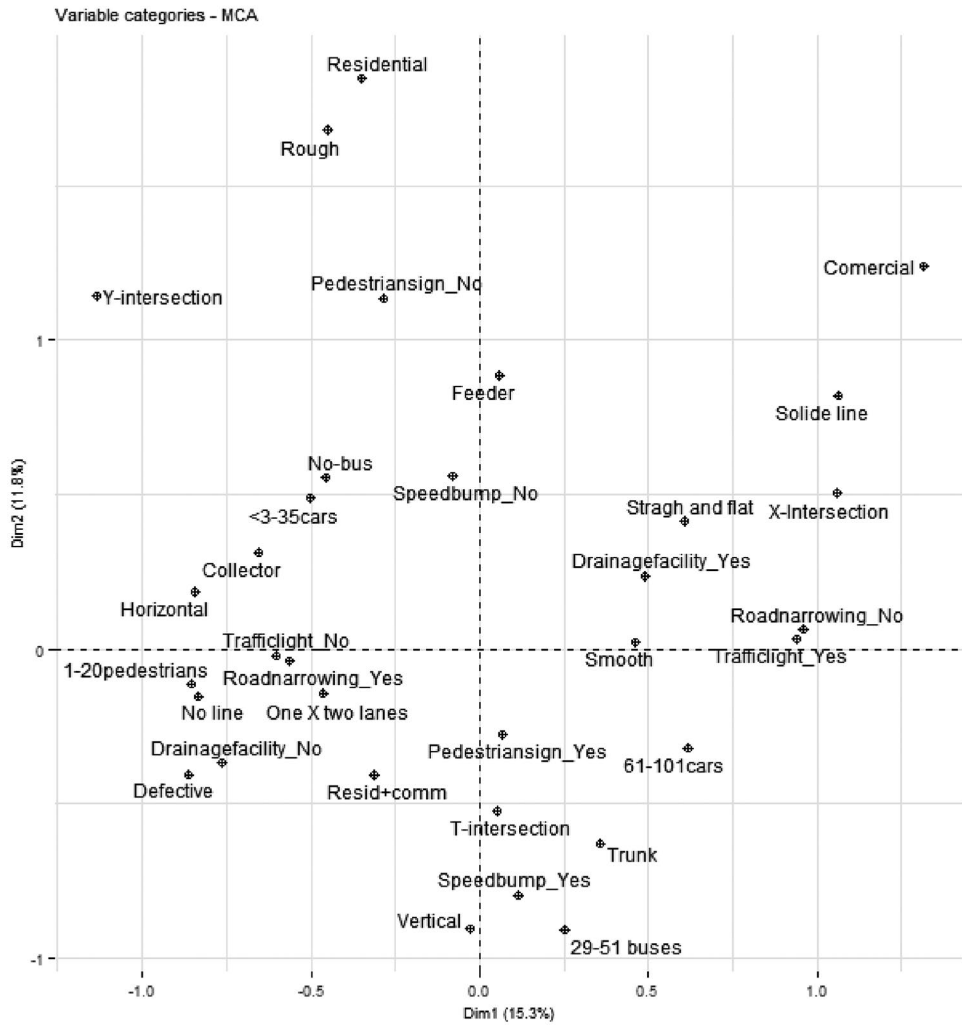

Figure 3. Multiple Correspondence Analyses factor map of the categories contributed to most variation in the first and second dimension of MCA.

pedestrian crossings and smooth road surfaces compared to the other clusters. About (78.0%) of the hotspots were characterized by straight and flat roads. Almost three quarters (75.0%) of the hotspots were characterized by presence of drainage facilities on both sides of the roads as well as the presence of traffic lights. More than half (58.0%) of the hotspots in cluster 3 were characterized by two-way separated roads with vehicles moving in the opposite direction. Furthermore, nearly (50.0%) of the hotspots in this cluster were associated with mixture of a higher numbers of cars and pedestrians.

Table 3 presents the distribution of crash characteristics associated with clusters of motorcycle injury hotspots. Cluster 2 was associated with a high rate of fatal injuries (18.6%), cluster 1 was associated with a greater number of severe injuries (42.8%) while cluster 3 was associated with overrepresentation of minor injuries (62.4%). There were significant differences between the level of injury severity and clusters ($p < 0.001$). Almost 60.0% of the crashes within the hotspots in all of the clusters were predominated by the side-way impact collisions. However, the difference was non-significant across the clusters ($p = 0.630$). Over 60.0% of the crashes within the hotspots occurred during the daytime. A high proportion (73.0%) of the crashes in cluster 2 involved the collision between two or more vehicles and the differences between the clusters were significantly ($p = 0.04$). Furthermore, the vast majority (56.5%) of crashes within the hotspots involved collisions between motorcycles and cars, followed by collisions between motorcycles and pedestrians (23.8%) and the lowest were collision between motorcycles with another motorcycle (9.0%).

Discussion

The current study used multiple correspondence and hierarchical cluster analysis to identify similar patterns among high-risk locations for motorcycle-related injuries based on road infrastructure and traffic density attributes. The results provide new insights of the joint effect of road infrastructure and traffic density attributes associated with motorcycle injury hotspots in LMIC settings. The results uncovered three distinct clusters of motorcycle injury hotspots that differed between each other in terms of road infrastructure and traffic density attributes. Our findings showed that

Table 3. Associations between crash characteristics within motorcycle injury hotspots and clusters (n = 727).

Variable	Cluster 1 (n = 15)	Cluster 2 (n = 19)	Cluster 3 (n = 12)	Total (n = 46)	P-value
No of crashes within hotspots	189	280	258	727	
Injury severity,					<0.001*
Minor	78(41.3)	129(46.1)	167(64.7)	374(51.4)	
Severe	81(42.8)	99(35.3)	68(26.4)	248(34.1)	
Fatal	30(15.9)	52(18.6)	23(8.9)	105(14.4)	
Time of day					
Daytime	119(63.0)	174(62.1)	155(60.1)	448(61.6)	0.804
Night-time	70(37.0)	106(37.9)	103(39.9)	279(38.4)	
Day of the week					
Monday	18(9.5)	44(15.7)	29(11.2)	91(12.5)	0.071
Tuesday to Thursday	80(42.3)	104(37.1)	122(47.3)	306(42.1)	
Friday to Sunday	91(48.2)	132(47.1)	107(41.5)	330(45.4)	
Number of vehicles involved					
Single vehicle collision	457(30.2)	73(26.1)	87(33.7)	212(29.2)	0.04*
Two or more vehicles	132(69.8)	207(73.9)	171(66.3)	515(70.8)	
Objects involved in collision					
MC with car	108(57.1)	163(58.2)	139(54.1)	410(56.5)	0.656
MC with pedestrian	45(23.8)	66(23.6)	66(25.7)	177(24.4)	
MC with motorcycle	17(9.0)	25(8.9)	23(9.0)	65(9.0)	
MC with three wheels	6(3.2)	7(2.5)	2(0.8)	15(2.1)	
MC with other objects	8(4.2)	13(4.6)	15(5.8)	36(5)	
Type of collisions					
Side-way impact	117(61.0)	170(60.7)	163(63.2)	310(61.8)	0.63
Rear end	30(15.9)	45(16.7)	50(19.3)	125(17.2)	
Head-on collision	25(13.2)	38(13.5)	30(11.6)	93(12.7)	
Others	17(9.0)	27(9.6)	15(5.8)	59(8.1)	

MC is referred to motorcycle, $p < 0.005$, significant by chi-square.

cluster 2 was associated with an overrepresentation of fatal and severe injuries. This cluster was characterized by several characteristics that in previous studies have been shown to indicate a high-risk road environment, e.g. an overrepresentation of trunk roads, unpaved, unseparated, two-way straight roads with T-intersections, vertical curves, smooth road surface, a combination of commercial and residential areas, and a mixture of different road users. Trunk roads including T-intersections have previously been shown to be associated with higher rates of fatal and severe injuries among motorcyclists (Abdul Manan & Várhelyi, 2015; Haque *et al.*, 2012). A possible explanation is that motorcyclists are more likely to absorb more kinetic energy released when they collide with buses and lorries on the trunk roads and therefore, suffer more severe consequences (Milling, 2016).In addition, data have shown that unseparated two-way roads may increase the likelihood of motorcyclists to collide with an incoming vehicle when switching from one lane to the other (Wu *et al.*, 2018)and also a higher risk of fatal injuries (Elvik, 2009; Olabarria *et al.*, 2015; Shankar, 2001).A French study showed that the risk of motorcycle crashes was four times higher among motorcycle riders who chose to lane filter on urban roads compared to those who did not (Clabaux *et al.*, 2017). Road geometric design, presence of horizontal or vertical curvature have also shown to increase the probability of motorcyclists losing control and running off the road (Rifaat *et al.*, 2012; Schneider *et al.*, 2010). Furthermore, studies have indicated that crashes that occurred on road sections with curves had more severe outcomes (Abdul Manan *et al.*, 2018; Gabauer, 2016; Indupuru, 2010). Curves usually decrease the visibility and limit the distance of sight on roadways, which could impair motorcyclists' control (WHO, 2008). Riding on a smooth surface has been shown to increase the probability of speeding as drivers sometimes tend to perceive that the smooth road surfaces are less risky, these findings are in line with studies from India and Malaysia (Saleh, 2010; Shaheed & Gkritza, 2014). Moreover, studies have shown that the presence of residential and commercial areas along the road network increases the number of pedestrians and their activities, which complicates the interaction between different road users within the area (Dai & Jaworski, 2016; Wedagama *et al.*, 2006).

Cluster 1 also had an overrepresentation of severe injuries compared to other clusters. To some extent, cluster 1 showed similar features to cluster 2 such as an overrepresentation of unseparated two-way roads, curves, a combination of commercial and residential areas, and a mixture of different road users. However, cluster 1differed by being characterized by a lower number of buses or Lorries, an overrepresentation of collector roads with no intersections, defective road surfaces, unpaved road shoulders and absence of drainage facilities. Collector roads are sharing similar features with trunk roads except that they have a lower number of buses and lorries. Thus, the crashes occurring on collector roads have shown to be more severe than those occurring on feeder roads (Daniello *et al.*, 2010). Also, defective road surfaces can increase the risk of motorcycle crashes due to lower friction between the tyres of motorcycle and the road surface, as well as the severity of injury due to the direct impact with the road surface during the crash (Haworth *et al.*, 2000). A study from China (Wu *et al.*, 2018) showed that the risk for motorcyclists of losing the control was 20 times higher when they encountered unexpected road surface hazards.

Furthermore, unpaved road shoulders have shown to increase the severity of injuries in cases where motorcyclists fall off their bikes during a collision (Abdul Manan *et al.*, 2018; Bishop & Amend, 2015).

Cluster 3 on the other hand was associated with more minor injuries. This cluster was characterized by an over-representation of feeder roads, separated two-way straight roads with smooth road surface and equipped with pedestrian crossing facilities and traffic lights compared with other clusters. The lower rate of severe injuries in cluster 3 could be attributed to the traffic environment demonstrated within this cluster. Feeder roads are characterised by a mixture of pedestrians, low speed, cars and motorcyclists (Mrema, 2011). Such traffic environment may be associated with a higher frequency of crashes, but with less severe outcome. Our findings was supported by findings from study in Malaysia which showed that feeder roads were associated with a relatively high rate of minor injuries compared to the trunk roads (Kamruzzaman, 2013). Similarly separated two-way roads were found to decrease the risk of head-on collision with severe injuries (Elvik, 2008; Harnen, 2011; Hosseinpour *et al.*, 2014; Olabarria *et al.*, 2015). Nevertheless, straight roads with smooth road-surface layout have shown to be associated with a higher rate of severe injuries (Aidoo *et al.*, 2013; Grzebieta, 2009; Jimenez *et al.*, 2015). However, an overrepresentation of minor injuries noted in this cluster and the disparities of these findings from other studies may be because the majority of these sections were located on feeder and within separated two-way roads which seem to be less dangerous for motorcycling. Moreover, studies on road safety have also shown that the presence of zebra crossings warns drivers to be cautious about the pedestrians and to reduce speed (Hamed, 2001; Varhelyi, 1998), which minimizes the risk of severe injury (Rifaat, 2014). In addition, other studies have shown that the presence of traffic lights has been linked to a reduction of both speed and conflicts among road users and consequently decreased the risk of serious injury (Chen *et al.*, 2012).

Regarding the association between the type of collisions and clusters of motorcycle-related injury hotspots, our findings revealed that side-impact collisions were the most predominant type of collisions in all the clusters. We found that almost 60% of the collisions forming the clusters were side-impact collisions. The higher rate of side-impact collisions reported in our study may be attributed to a tendency of car drivers to deny the right of way to motorcyclists (Crundall *et al.*, 2008) or a sudden unsafe lane change by the motorcyclists. This finding is consistent with previous studies which have shown that side-impact collisions are the most common type of motorcycle collision (Evangelou, 2006; Greve, 2018).

As the hotspots of motorcycle-related injuries did not share similar road infrastructure characteristics and traffic density, the findings from the study support that it is possible by statistical methods to visualize and characterize high-risk locations based on their road infrastructure and traffic density attributes. The results also give an insight about the complexity in explaining why hotspots vary according to injury severity and can support the prioritization of needed preventive efforts in order to improve road traffic safety for motorcyclists in low and middle-income countries.

We acknowledge some limitations in this study, which is, attributed to the use of police crash data such as under-reporting of crash events and recall bias. In the country like other LIMICs, all major road traffic incidents causing death, injury or property damage are required to be reported to police. Reporting of road traffic injury incidences are often done by victims themselves, witnesses or police at the scene. Also, the health care providers are required to inquire police form number 3 (PF3) which indicates that the victims reported the incident to the police before given the service, and if the victim does not have a PF3, the health care providers should hold the patient until their relatives complete it. This system of reporting could miss out some cases as the reporting depends mainly on willingness of victims and heath care providers. Evidence has suggested that there are high rates of underreporting of minor injuries in police-reported data. However, since the data were collected from the same source, the assumption is that underreporting of crash data would be randomly distributed all over the city and therefore the misclassification would not systematically affect the identification of hotspots and clusters in the current study. On top of underreporting of minor injuries, we noted a large amount of missing information specifically related to age and sex. About 26% of the injured persons had missing data on age in the data set. Missing information on the address of crashes may have resulted in an underestimation of the number of crashes involved at a particular hotspot. However, the percentage of locations that could not be mapped because of missing addresses for the locations of the crashes was as low as 2% and these locations were distributed over different traffic police stations where the crash data were extracted. Another limitation is that injury severity was recorded by non-medical personnel and therefore, this could result in misclassification. However, it is impossible to speculate on the extent to which this could have affected our results. One of the strengths of this study was that we visited each hotspot and gathered data on the road infrastructure and traffic density that were used for assessing the attributes that influenced the occurrence of the hotspots.

Conclusion

This study uncovered three distinct clusters of motorcycle injury hotspots that differed in terms of road infrastructure and traffic density attributes. It was noted that two of the clusters (1 and 2) consisted of more hazardous road environments which were more unsafe for motorcyclists. These clusters had an overrepresentation of trunk roads, unseparated two-way roads, roads going through residential and commercial areas, and a mixture of different road users. Cluster 3 on the other hand consisted of sites where crashes had less severe outcomes. The findings of this study can support prioritisation of prevention strategies for road traffic injuries among motorcyclists in LMIC, especially in settings with a rapid increase of motorcyclists.

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Author contributions

FF coordinated the design of the study project, data collection, analysis, and drafted the manuscript. MH participated in the development of study design, assisted and supervised the data analysis, drafting of the manuscript, editing, and proofreading, HYB participated in the interpretation of the results and comments on the manuscript and CM contributed to writing the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability

Data available on request due to privacy/ethical restrictions

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