Multivariate Association in Road Traffic Crashes and the Policy Implication for Maximum Remedial Effect

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Abstract

In 2010, the governments of the world declared 2011-2020 as the Decade of Action for Road Safety. The unanimous support for this Decade of Action from member states explains the growing awareness of the devastating scale of road traffic injuries as a global public health and development problem. Despite the enormous toll exacted by road traffic injuries, they have for many years been neglected by global health and development agendas, and funding for interventions has not been commensurate with the scale of the problem. Strategies do exist, however, that have proven to reduce road traffic injuries and a number of countries have successfully used these to reduce their road traffic deaths. The objective of this study is to use the Oyo State-Nigeria evidence-based case to explain the need to take cognisance of neighbourhood characteristics in policy designs and decision- making to enhance significant remedial effect from interventions in an attempt to reduce road traffic injuries and deaths. The characteristics investigated include major road lengths, travel density, residential population and the area of administration. The study concludes that spillover effects do exist in road traffic crashes (RTC) within spatial units across geographical regions – as such, neighbourhood characteristics cannot be ignored when planning for intervention. Apparently, the need to incorporate spatial analysis with existing strategies to achieve maximum remedial effect cannot be over emphasised. These results should enable the orientation of safety and injury prevention policies targeted towards reducing the frequencies of RTC.

Keywords: road traffic crashes, spillover effects, interventions, development, policies

Sumário

Em 2010, os governos do mundo declararam o período de 2011-2020 como a Década de Acção para a segurançanas estradas. O apoio unânime para esta Década de Acção dos Estados membros explica aconsciência crescente da escala devastadora que os acidentes de trânsito têm impactado na saúde pública mundialassim como nos problemas de desenvolvimento. Apesar do enorme número de acidentes de trânsito, por muitos anos eles foram negligenciados por agendas globais preocupados com a saúde e desenvolvimento e o financiamento paraintervenções para a redução destes acidentes não foi compatível com a dimensão do problema. Existem estratégias, no entanto, que provaram reduzir lesões no trânsito e vários países têmutilizado com sucesso estas estratégias para reduzir mortes no trânsito. O objectivo deste estudo é a utilização do caso do Estado de Oyo na Nigéria, baseando se em evidências para explicar a necessidade de se tomar conhecimento das características do bairro para desenhar projectos de políticas que permitirão a tomada de decisões para melhorar de forma significativa as intervenções necessárias para reduzir os acidentes de viação *e as lesões e mortes dai resultantes. Entre as características investigadas incluem se o comprimento das estradas, a intensidade do transito, a população que reside nas proximidades das vias assim como a sua administração. O estudo conclui que existem efeitos colaterais em acidentes de trânsito dentro de unidades espaciais em todas as regiões geográficas - como tal, características da vizinhança não podeser ignoradas quando se planeja para a intervenção. Aparentemente, a necessidade de incorporar a análise espacialcom as estratégias existentes para atingir efeito corrector máxima não podem ser mais enfatizado. Estes resultados devem permitir a orientação das políticas de segurança e de prevenção de lesões direccionados para reduzir as frequências de acidentes rodoviários.*

Keywords: acidentes de trânsito, os efeitos colaterais, intervenções, desenvolvimento, políticas

Introduction

In 2010, the governments of the world declared 2011–2020 as the Decade of Action for Road Safety. The unanimous support for this Decade of Action from Member States explains the growing awareness of the devastating scale of road traffic injuries (RTI) as a global public health and development problem. The global status report on road safety presents information on road safety from 182 countries, accounting for almost 99% of the world's population with only 28 countries, that is, 7% of the world's population, having comprehensive road safety laws. The five key risk factors focus on drinking and driving, speeding, failure to use motorcycle helmets, non-use of seat belts and failure to use child restraints[1].

Globally, RTI are estimated to be the eighth leading cause of death. They are the leading cause of death for young people aged 15-29 years, and as a result, take a heavy toll on those entering their most productive years. Economically disadvantaged families are hardest hit by both direct medical costs and indirect costs such as lost wages that result from these injuries. At the national level, RTI result in considerable financial costs, particularly to developing economies. Indeed, RTI are estimated to cost low and middle income countries between 1-2% of their gross national product, estimated at over US$100 billion a year. Despite the enormous toll exacted by RTI, they have for many years been neglected by global health and development agendas, and funding for interventions has not been commensurate with the scale of the problem. This is despite the fact that RTI are largely preventable and that the evidence base for effective interventions is extensive. However, strategies do exist that are proven to reduce RTI and a number of countries have successfully used these strategies to reduce their road traffic deaths. Reports, however, show that there has been no overall reduction in the number of people killed on the world's roads (Global Status Report on Road Safety, 2013).

To enhance maximum remedial effects, there is, however, a need to examine the impact of

1 For more information see www.who.int/iris/bitstream/10665/78256/1/9789241564564_eng and also, http://whqlibdoc.who.int/publications/2009/9789241563840_eng.pdf; www.who.int/violence_injury.../road_safety_status/2013/report/en/; www.who.int/violence_injury_prevention/road_safety_status/2013/en/

environmental risk factors at the grassroots. For instance, Nigeria has one of the deadliest roads in the world after it was ranked 191 out of 192 countries in a road safety survey. The low ranking highlights Nigeria's inadequate investment in infrastructure with Road Traffic Crash (RTC) data on death rates, showing at least 162 deaths per 100 000 of the Nigerian population. The World Health Organisation (WHO) estimated that over 1.3 million people were killed by RTC and 50 million injured on the world's roads annually, adding that over 80 percent of the figure occurred in developing countries, with Africa having the highest death rate. WHO predicted that if countries did nothing to stem the tide, death by RTC would increase by 65 percent from 2015 to 2020, overtaking malaria and tuberculosis (The Africa Report, 2013).

Sukhai, Jones, Love & Haynes (2011) investigated the factors that explain temporal variations in road traffic fatalities, using weekly data from the period 2002-2006 for the nine provinces in South Africa. Kruskal, Wallis H. & Mann Whitney U. tests were used to compare fatality counts across the categories for the temporal explanatory variables. Multivariate regression models were titled to examine between province variations in weekly road traffic fatalities (RTFS). Non-linear auto-regression exogenous (NARX) models were also used to examine between province variations in weekly RTFS using ordinary least squares regression. Findings suggest that patterns are predominantly driven by temporal variations in traffic flows, although increased alcohol consumption during holiday periods may also be important.

To reduce accidents, casualties and improve safety and security on roads, highway improvement project selection usually requires screening thousands of road segments with respect to crashes for further analysis and final selection into improvement projects. Kelle, Schneider, Raschke & Shirazi (2013) described a two-step procedure for selecting potential accident locations for inclusion in highway improvement projects. The first step of the proposed methodology uses odds against observing a given crash count, injury count, run-off road count and so on as measures of risk, and a multi-criteria pre-selection technique with the objective to decrease the number of prospective improvement locations. The second step is based on a composite efficiency measure of estimated cost, benefit and hazard assessment under budget constraint. To demonstrate the two-step methodology, the study analysed four years of accident data at 23 000 locations where the final projects were selected out of several hundred potential locations.

Also, Chandran *et al*. (2013) calculated years of life lost and reduction in life expectancy using population and crash data from Brazil's ministries of health and transport to enhance prioritisation of RTC. The potential for crash mortality reduction was calculated for hypothetical scenarios, reducing death rates to those of the best performing region and age category. Road traffic crashes reduced the life expectancy for males at birth by 0.8 years and 0.2 years for females. The study concluded many years of life lost for men and women could be averted if all rates matched those of the lowest risk region and age category.

For the purposes of visualisation, our focus is on the linear association between a variable at a location and the corresponding spatial lag for the other variable. In this context, the usual singly-standardised (row-standardised) form of the spatial weights matrix can be used, which yields an interpretation of the spatial lag as an average of neighbouring values. Also, the cross-product statistic can be re-scaled by dividing by the sum of squares for the first variable. This yields a multivariate counterpart of a Moran-like spatial autocorrelation. This concept of multivariate spatial correlation thus centres on the extent to which values for one variable observed at a given location shows a systematic (more than likely under spatial randomness) association with another variable observed at the neighbouring locations. This multivariate spatial correlation can be considered in addition to or instead of the usual (non-spatial) correlation between the two variables at the same location (Anselin, Syabri & Smirnov (n.d.)).

The significance of this multivariate spatial correlation can be assessed in the usual fashion by means of a randomisation (or permutation) approach. The observed values for one of the variables are randomly reallocated to locations and the statistic is recomputed for each such random pattern. The resulting empirical reference distribution provides a way to quantify how extreme the observed statistic is relative to what its distribution would be under spatial randomness. This leads to a straightforward generalisation of Anselin's Moran Scatterplot and Local Moran statistics (Anselin (1995) and Anselin (1996)).

The objective of this study is to use the Oyo State-Nigeria evidence-based case to explain the need to take cognisance of neighbourhood characteristics in policy designs and decision-making to enhance significant remedial effect from interventions in an attempt to reduce RTI and deaths. The characteristics investigated include major road lengths, travel density, residential population and the area of administration.

The basic underlying assumption is that there is a spillover effect across the study area. The neighbourhood characteristics will focus on the queen and rook contiguity-based weight matrices. The original measure for spatial dependence, or more precisely, spatial autocorrelation, advanced by Moran (1948) and Geary (1954) were based on the notion of binary contiguity between spatial units. According to this notion, the underlying structure of neighbours is expressed by 0-1 values. If two spatial units have a common border of non-zero length, they are considered to be contiguous, and a value of 1 is assigned.

This definition of contiguity obviously assumes the existence of a map, from which the boundaries can be discerned. For an irregular arrangement of spatial areal units, this is fairly straightforward. However, when the spatial units refer to a regular grid or a collection of irregularly arranged points, the determination of contiguity is not unique.

Clearly, there are a great variety of ways in which binary contiguity can be formalised. For example, consider the regular grid and associated centroids, a common border between a cell and surrounding cells can be considered in a number of different ways. It could be taken as a common edge when the surrounding cells are contiguous; alternatively, a common vertex could be considered, or a combination of both notions could be used. In an analogy with the game of chess, these situations have been called the rook case, the bishop case and the queen case.

When the spatial units consist of points such as cities in an urban hierarchy that are regularly or irregularly spaced over the system, the meaning of contiguity can be derived from the notion of the shortest path on a network (or graph) formed by connecting the points, such as the network formed by the dashed lines. Nodes on the network are considered as neighbours if they are within a given maximum (shortest path) distance of each other. Alternatively, the boundaries generated by various spatial tessellations could be considered to determine contiguity. These tessellations consist of an areal division of the spatial system into polygons or cells that are related in a systematic manner to the location of the points. Consequently, a map of polygons replace the original representation of spatial units by points, for which contiguity can be determined in the usual fashion.

This study is organised as follows: introduction, materials and methods, findings and discussion, conclusion and recommendation.

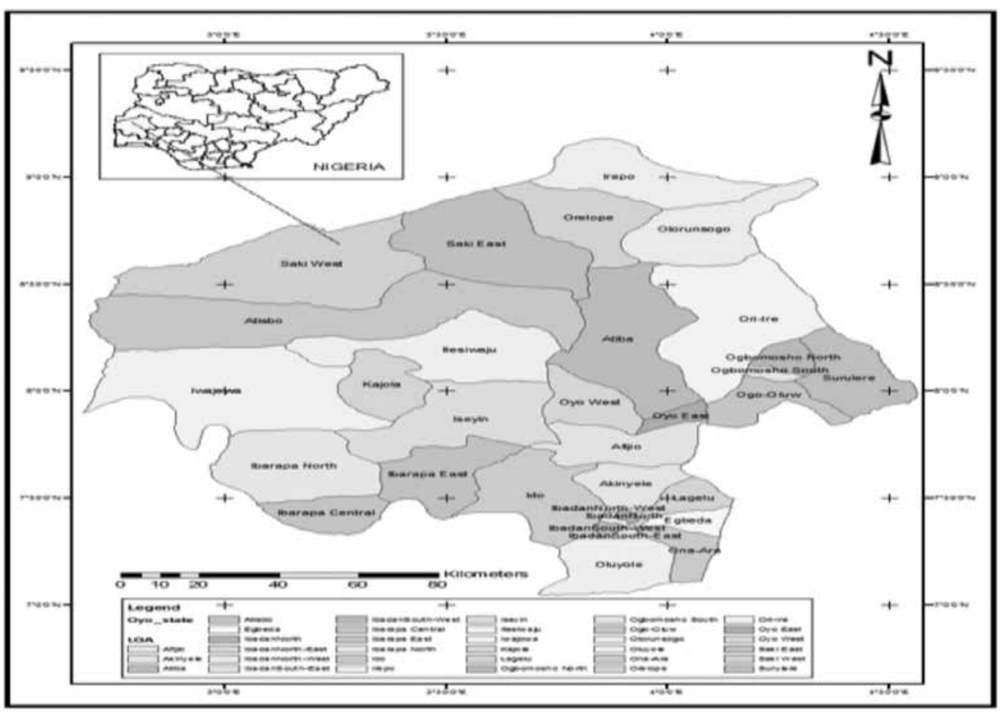
Materials and Methods

This section contains details of the study area, data description and methods.

Case Study

Oyo State is located within the Southwest Geopolitical region of Nigeria in West Africa. The study area is as described in Figure 1. The State has 33 local government authorities (LGA); each LGA has at least two neighbours based on the queen and rook criteria as shown in Tables 1 and 2.

Figure 1: The Oyo State map



The Federal Road Safety Commission (FRSC) RS11.3 Oyo sector command with headquarters at Eleyele, Ibadan in Oyo State comprised ten unit commands; each unit command has designated service routes within the LGAs. The unit commands and the LGA they oversee are as follows: RS11.30 Eleyele unit command oversees the Ibadan North West and Ibadan South West; RS11.31 Ogbomoso unit command, Ogbomoso South, Ogbomoso North, Ogo-Oluwa and Surulere; RS11.32 Oluyole command, Ibadan South East, Oluyole and Ona Ara; RS 11.33 Iddo unit command, Ibarapa North, Ibarapa Central, Ibarapa, East and Ido; RS11. 34 Mokola unit command, Ibadan North and Ibadan North East; RS 11.35 Egbeda unit command, Egbeda and Lagelu; RS 11.36 Saki unit command, Saki West, Saki East, Orelope, Atisbo, Iwajowa, Kajola and Itesiwaju; RS11.37 Kisi unit command, Irepo, Olorunsogo, and Orire; RS11.38 Atiba unit command, Atiba, Afijio, Oyo East, Oyo West and Iseyin ; RS 11.39 Moniya unit command Akinyele LGAs respectively, FRSC (2013).

Table 1: Queen Neighbours for Each of the 33 Local Government Areas in Oyo State

S/N	Local Government Area	Neighbours
1	Irepo	Orelope and Olorunsogo
2	Saki West	Atisbo and Saki East
3	Ibarapa Central	Ibarapa North and Ibarapa East
4	Ogbomoso North	Surulere, Orire and Ogbomoso South
5	Kajola	Itesiwaju, Iseyin and Iwajowa
6	Egbeda	Ona Ara, Lagelu and Ibadan North East
7	Saki East	Saki West, Atisbo, Atiba and Orelope
8	Orelope	Irepo, Olorunsogo, Saki East and Atiba
9	Olorunsogo	Orire, Atiba, Orelope and Irepo
10	Ibarapa North	Iwajowa, Iseyin, Ibarapa East and Ibarapa Central
11	Ogbomoso South	Ori-ire, Ogbomoso North, Surulere and Ogo Oluwa
12	Surulere	Ori-ire, Ogo-Oluwa, Ogbomoso North and Ogbomoso South
13	Ibadan North	Akinyele, Ibadan North East, Ibadan North West and Lagelu
14	Ibadan South East	Ibadan North East, Ona Ara, Oluyole and Ibadan South West
15	Lagelu	Akinyele, Ibadan North, Egbeda and Ibadan North East
16	Ona Ara	Ibadan North East, Ibadan South East, Egbeda and Oluyole
17	Oluyole	Ibadan South East, Ona Ara, Ibadan North East, Ibadan South West and Ido
18	Ibadan South West	Ido, Ibadan North East, Ibadan South East, Oluyole and Ibadan North West
19	Ibadan North West	Ibadan South West, Ibadan North East, Ido, Akinyele and Ibadan North

S/N	Local Government Area	Neighbours
20	Akinyele	Afijio, Ido, Lagelu, Ibadan North and Ibadan North West
21	Ogo-Oluwa	Surulere, Ogbomoso South, Orire, Oyo East and Afijio
22	Oyo East	Ogo-Oluwa, Orire, Oyo West, Afijio, and Atiba
23	Oyo West	Afijio, Oyo East, Atiba, Itesiwaju and Iseyin
24	Atisbo	Saki West, Iwajowa, Atiba, Itesiwaju and Saki East
25	Iwajowa	Atisbo, Itesiwaju, Kajola, Iseyin and Ibarapa North
26	Ibarapa East	Ibarapa North, Ibarapa Central, Iseyin, Ido and Afijio
27	Itesiwaju	Atisbo, Kajola,Iwajowa, Atiba, Iseyin and Oyo West
28	Ido	Ibarapa East, Iseyin, Afijio, Akinyele, Oluyole, Ibadan North West and Ibadan South West
29	Afijio	Oyo West, Oyo East, Ogo-oluwa, Akinyele,Ido, Iseyin and Ibarapa East
30	Ori-ire	Olorunsogo, Atiba, Oyo East, Ogo-Oluwa, Ogbomoso South, Ogbomoso North and Surulere
31	Ibadan North East	Egbeda, Ona Ara, Lagelu, Ibadan North, Oluyole, Ibadan South East, Ibadan South West and Ibadan North West
32	Iseyin	Ibarapa North, Ibarapa East, Kajola, Iwajowa, Itesiwaju, Afijio, Ido and Oyo West
33	Atiba	Ori-ire, Olorunsogo, Oyo East, Orelope, Saki East, Atisbo, Itesiwaju and Oyo West

Table 2: Rook Neighbours for Each of the 33 Local Government Areas in Oyo State

S/N	Local Government Area	Neighbours
1	Irepo	Orelope and Olorunsogo
2	Saki West	Atisbo and Saki East
3	Ibarapa Central	Ibarapa North and Ibarapa East
4	Ogbomoso North	Surulere, Orire and Ogbomoso South
5	Kajola	Itesiwaju, Iseyin and Iwajowa
6	Egbeda	Ona Ara, Lagelu and Ibadan North East
7	Saki East	Saki West, Atisbo, Atiba and Orelope
8	Orelope	Irepo, Olorunsogo, Saki East and Atiba
9	Olorunsogo	Orire, Atiba, Orelope and Irepo
10	Ibarapa North	Iwajowa, Iseyin, Ibarapa East and Ibarapa Central
11	Ogbomoso South	Ori-ire, Ogbomoso North, Surulere and Ogo Oluwa
12	Surulere	Ori-ire, Ogo-Oluwa, Ogbomoso North and Ogbomoso South
13	Ibadan North	Akinyele, Ibadan North East, Ibadan North West and Lagelu
14	Ibadan South East	Ibadan North East, Oluyole and Ibadan South West

S/N	Local Government Area	Neighbours
15	Lagelu	Akinyele, Ibadan North, Egbeda and Ibadan North East
16	Ona Ara	Ibadan North East, Egbeda and Oluyole
17	Oluyole	Ibadan South East, Ona Ara, Ibadan South West and Ido
18	Ibadan South West	Ido, Ibadan North East, Ibadan South East, Oluyole and Ibadan North West
19	Ibadan North West	Ibadan South West, Ibadan North East, Ido, Akinyele and Ibadan North
20	Akinyele	Afijio, Ido, Lagelu, Ibadan North and Ibadan North West
21	Ogo-Oluwa	Surulere, Ogbomoso South, Orire, Oyo East and Afijio
22	Oyo East	Ogo-Oluwa, Orire, Oyo West, Afijio, and Atiba
23	Oyo West	Afijio, Oyo East, Atiba, Itesiwaju and Iseyin
24	Atisbo	Saki West, Iwajowa, Atiba, Itesiwaju and Saki East
25	Iwajowa	Atisbo, Itesiwaju, Kajola, Iseyin and Ibarapa North
26	Ibarapa East	Ibarapa North, Ibarapa Central, Iseyin and Ido
27	Itesiwaju	Atisbo, Kajola,Iwajowa, Atiba, Iseyin and Oyo West
28	Ido	Ibarapa East, Afijio, Akinyele, Oluyole, Ibadan North West and Ibadan South West
29	Afijio	Oyo West, Oyo East, Ogo-Oluwa, Akinyele, Ido and Iseyin.
30	Ori-ire	Olorunsogo, Atiba, Oyo East, Ogo-Oluwa, Ogbomoso South, Ogbomoso North and Surulere
31	Ibadan North East	Egbeda, Ona Ara, Lagelu, Ibadan North, Ibadan South East, Ibadan South West and Ibadan North West
32	Iseyin	Ibarapa North, Ibarapa East, Kajola, Iwajowa, Itesiwaju, Afijio and Oyo West
33	Atiba	Ori-Ire, Olorunsogo, Oyo East, Orelope, Saki East, Atisbo, Itesiwaju and Oyo West

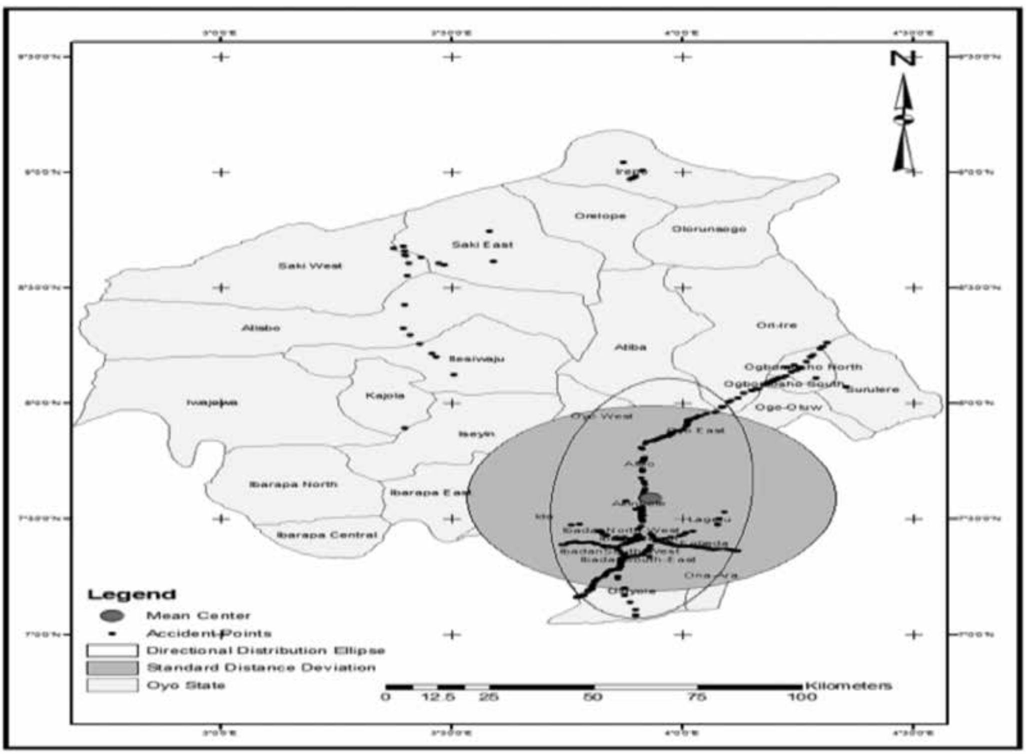
Data

Data for RTC 2012 obtained from RS11.3 FRSC Oyo sector command was used for this study FRSC (2013). The study area is as indicated in Figure I. The 2012 traffic volume for the command was used. This research had good potential to obtain quality results as good cooperation from the FRSC was enjoyed. The study focused on the area of land encompassing each LGA, total length of major roads within each LGA, travel densities within each LGA and the residential population for every LGA, and these were sourced from the National Bureau of Statistics (NBS) bulletin NBS (2007).

The approximate locations of RTC were estimated from the record obtained from the RS 11.3 Oyo FRSC command. Generally, the record provides an indicative description of the locality where the accident occurred and in some cases the site was described using the nearest landmarks such as filling stations, roundabouts, stores, markets, garages, institutions or road intersections. Therefore, using the nearest landmarks or locality information provided in the record together with the Google Earth image, the existing digital road network, and the knowledge of the area of study, it was easy to place points on the approximate locations where the crashes occurred (Figure 2).

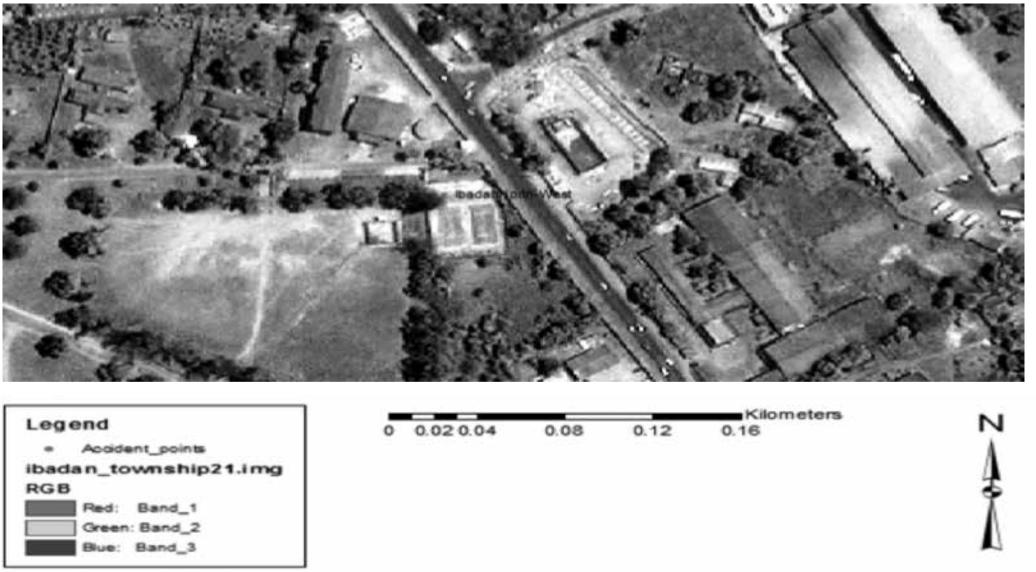
The Google Earth image was particularly helpful because it provided a photographic view of the area of study together with the associated landmarks and road networks. Through the instrumentality of global positioning system (GPS) and the information on locations of crashes for each of the unit commands, the coordinates of crash locations were obtained on the geographic coordinates system of the world.

Figure 2: The mean centre, standard distance deviation and standard deviational ellipse of accident points in Oyo State, Nigeria.



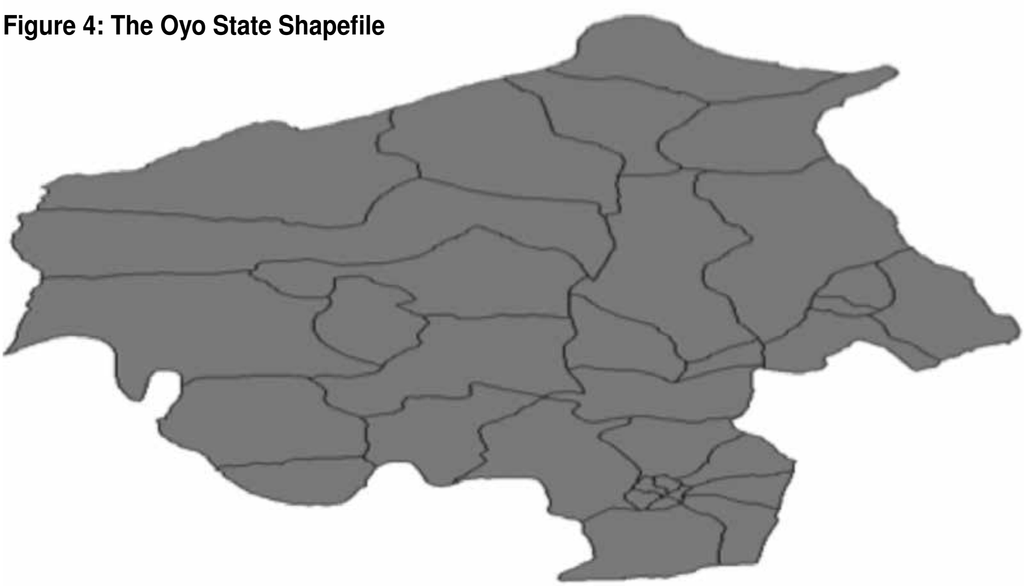
The coordinate locations generated were subsequently exported into ArcGIS where they were plotted as point locations, which represent accident crash locations. These were overlaid on the road network of the LGAs of Oyo State. This made it possible to clip the Oyo State geo-referenced map within the ArcGIS environment to ascertain where each accident location falls. Therefore, the number of accident points within each LGA was counted and recorded accordingly. The Ibadan satellite imagery was used as a guide (Figure 3).

Figure 3: Portion of the Oyo State Quick Bird Satellite Imagery



The geographic information system (GIS) was used to create a polygon shape file (Figure IV) for the study area. The shape file was used to create a spatial contiguity weight matrix based on the queen and rook criteria. This was used to determine neighbours as in Tables 1 and 2. The lengths of the roads and the area encompassing each LGA were calculated using the measuring tool in the software environment.

Figure 4: The Oyo State Shapefile



Population is defined as the residential population figures for each LGA as reported by NBS for the 2006 population census in Nigeria. Travel density is defined as traffic count for each FRSC unit command divided by total major road length in kilometres within each LGA. Major road length is the total length of roads in kilometres from each settlement to another within each LGA. Area is defined as the area per square kilometre encompassing each LGA. Accident is defined as the total cases of RTC recorded in each LGA whose location was identified by recording the latitudes and longitudes. The logarithms of all the variables were taken for the purpose of this study.

Methods

The histogram, spatial auto correlation and random permutations methods will be adopted.

Moran's I

This global measure of spatial dependence (spatial auto correlation) was developed by Moran (1948). The index measures spatial dependence based on feature locations and attribute values. The measure evaluates whether the pattern is clustered, dispersed or random. The null hypothesis is that the distribution of accidents or accident rates on a segment is not auto correlated. When the z-score or p-value indicates statistical significance, a positive Moran's I index value indicates a tendency towards clustering while a negative Moran's I index value indicates a tendency toward dispersion. The Moran's I statistic is structured as a Pearson product moment correlation coefficient, plus *W,* the contiguity weights matrix. *Y* is a covariance matrix, that is, the relation between the spatial units is calculated as $(y_i - \bar{y})(y_j - \bar{y})$. The obtained measure is scaled by

$$\frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \left[\sum_{i=1}^{n} (y_i - \bar{y})^2 \right] \quad (1)$$

By convention, $i \neq j$

As a result,

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (2)$$

where y_1 = the value of variable y on segment i, y = the mean of variable y, n = the number of segments, w_{ij} = a weight indicating if segment i is connected to segment j (e.g. 1) or if it is not (e.g. 0). The summation operators are for i = 1, 2, ..., n and j = 1, ..., n in all cases.

The expected value of I is $E(I)$ = (-1)/n-1. The variance of I under the assumption of normally distributed data is:

$$Var(I) = \frac{n^2 s_1 - n s_2 + 3(\sum_i \sum_j w_{ij})^2}{\left(\sum_i \sum_j w_{ij}\right)^2 (n^2 - 1)} \qquad (3)$$

where, $s_1 = \frac{1}{2}\sum_i \sum_j (w_{ij} + w_{ji})^2$ and $s_2 = \sum_i \left(\sum_i w_{ij} + \sum_j w_{ji} \right)^2$

Local Moran's I and Z-Score are given below where $\bar{y}$ is mean value and s^2 is variance.

$$I_i = \frac{(y_i - \bar{y})}{s^2} \sum_j w_{ij}(y_j - y) \qquad (4)$$

while,

$$Z(I_i) = I_i - E(I_i) / \sqrt{Var(I_i)} \qquad (5)$$

When two segments connect, a value of 1 represents this, and if not, 0 is entered in the weight matrix. For any set of n segments of a linear route, there will be 2(n−1) joins. If the focus of the analysis is not a single linear route, but an entire network, then the connectivity of segments to each other may need to be identified by inspection. Once identified, a binary connection matrix of segments represents the presence or absence of connections.

Multivariate Spatial Correlation

A multivariate coefficient of spatial autocorrelation between two standardised random variables z_k and z_l is defined as:

$$m_{kl} = z_k' W^s z_l \qquad (6)$$

where $z_k = [x_k - \bar{x}_k]/\sigma_k$ and $z_l = [x_l - \bar{x}_l]/\sigma_l$ have been standardised such that the mean is zero and standard deviation equals one, and W^s is a doubly standardised (or, stochastic) spatial weights matrix. The weights matrix defines the 'neighbour set' for each observation (with non-zero elements for neighbours, zero for others) and has zero on the diagonal by convention. This yields a multivariate counterpart of a Moran-like spatial autocorrelation statistic as:

$$I_{kl} = \frac{z_k' W z_l}{z_k' z_k} \qquad (7)$$

or $$I_{kl} = \frac{z_k' W z_l}{n} \qquad (8)$$

with n as the number of observations, and W as the familiar row-standardised spatial weights matrix.

Generalised Moran Scatterplot

The Moran Scatterplot visualises a spatial autocorrelation statistic as the slope of the regression line in a scatterplot with the spatial lag on the vertical axis and the original variable on the horizontal axis (using the variables in standardised form). This follows from the structure of Moran's I statistic, which has a cross product between z and Wz in the numerator, and the sum of squares of z in the denominator. For standardised variants, this corresponds to the slope of a regression line of Wz on z.

A multivariate generalisation of this plot follows by using Wzl on the vertical axis and z_k on the horizontal axis. The slope of the linear regression through this scatterplot equals the statistic

$$I_{kl} = \frac{z_k' W z_l}{z_k' z_k} \qquad (9)$$

In addition, the four quadrants of the scatterplot correspond to four types of multivariate spatial association, depending on how the value for z_k at i compares to the corresponding spatial lag for z_l. Relative to the mean (all values are standardised), this suggests two classes of positive spatial correlation or spatial clusters (high-high and low-low), and two classes of negative spatial correlation, or spatial outliers (high-low and low-high). Points in each of the quadrants can be linked with their location on a map or on any of the other statistical graphs, such as a non-spatial scatterplot between z_l and z_k. Inference can be based on a permutation approach.

Findings and Discussion

Things to be considered for significant remedial effect in policy design.

Spatial Pattern

Figures 5 and 6 shows the familiar bell-like shape characteristic of a normally distributed random variable, with the values following a continuous colour ramp. The histogram is classified into 7 categories. The figures by the side indicate the number of observations falling in each category. The observations themselves are shown in brackets. For instance, in Figure 5, for the first category 2(3), three observations have two neighbours.

The significance of taking cognisance of neighbourhood characteristics is illustrated in these figures: even though the shape file is the same, the distribution of the two histograms is not exactly the same. The only corresponding observations are 2(3), 4(10) and 7(3). This depicts the distribution of a variable for a selected subset of locations on the map, possibly suggesting the existence of spatial heterogeneity. A particular approach is likely to yield different results. To discover the most effective approach for dispensing intervention measures, there is a need to investigate the relationships that exist between localities, namely, spatial units (LGAs), before remedial effects can be administered.

For instance, from Table 1 corresponding to Figure 5, Irepo LGA has two neighbours: Orelope and Olorunsogo. Technically, the three LGAs must be observed as the same when administering any form of safety and security measure. Otherwise significant remedial effect cannot be achieved.

Figure 5: Connectivity histogram (Queen)

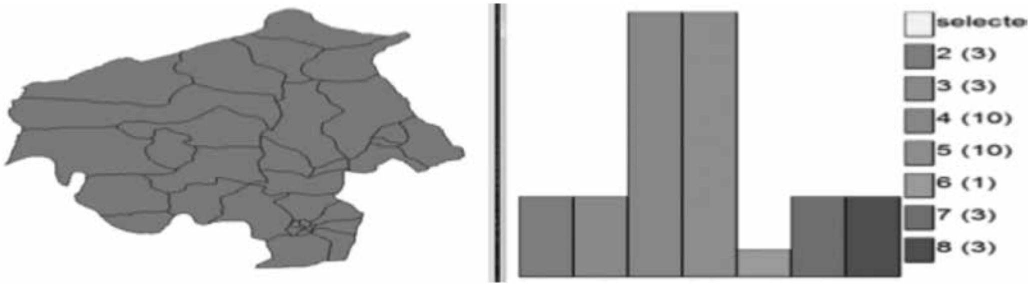
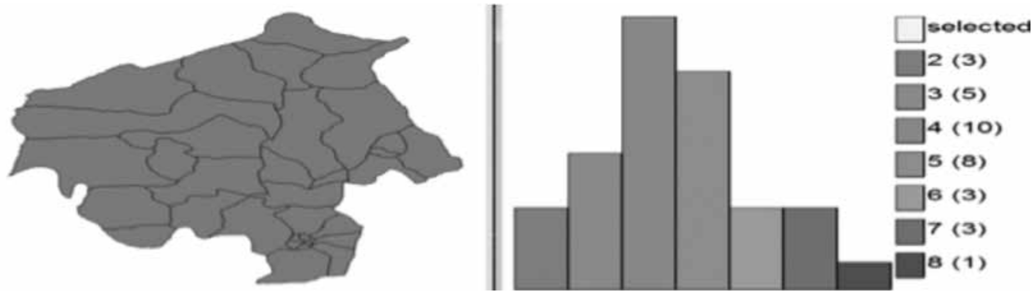


Figure 6: Connectivity histogram (Rook)



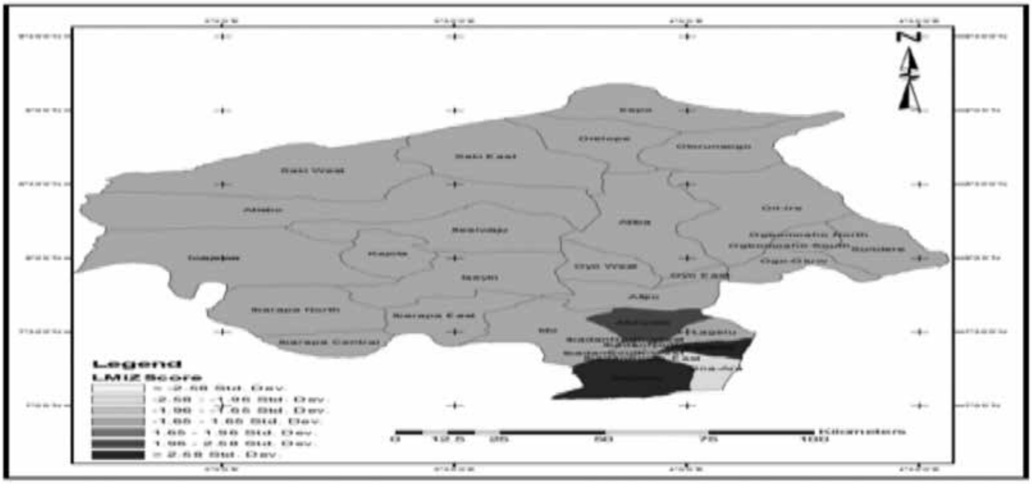
Spatial Dependencies

To achieve maximum remedial effect, spatial units with high or low-low similarities show positive correlation and must receive intervention simultaneously, whereas, spatial units with high-low or low-high relationships show negative correlation and need not receive intervention simultaneously.

For instance, the spatial dependence values associated with the 2012 RTC in Oyo State, Nigeria are given in the next section. The Moran's I Index equalled 0.19; Z score equalled 2.61 and P value equalled 0.01. The null hypothesis of randomness was rejected. There is less than 1%

likelihood that this clustered pattern could be a result of random chance. Therefore, it is concluded that the spatial pattern is clustered, as such; there is strong spatial dependence across the study area (see Figure 7).

Figure 7: Map showing concentration level of road traffic crashes



Results reveal high-high values of concentration of accidents clustering within Egbeda, Oluyole and Akinyele LGAs. The low-high concentration for Ona Ara LGA is an indication of clustering from low to high (see Table 3).

Table 3: Representing Moran's Spatial Dependence for RTC (2012) Among LGA in Oyo State, Nigeria

LGA	LMi Index	LMiZ Score	LMi P Value	Concentration
Egbeda	+10.60	+4.49	0.000	HH
Oluyole	+07.25	+3.39	0.001	HH
Akinyele	+05.19	+2.13	0.033	HH
Ona Ara	- 05.54	-2.17	0.030	LH

Key: *HH =High-High; LH= Low-High*

Going by the results above, it will be necessary to apply every form of road safety and security intervention to Egbeda, Oluyole and Akinyele LGAs simultaneously and at the same scale if maximum remedial effect is expected. Because Ona Ara LGA has a low-high concentration, ignoring it at this moment will have no impact on achieving a significant remedial effect, but failure to achieve significant remedial effect in the former LGAs could lead to a concentration of RTC at future dates.

Linear Associations

The degree of linear associations are examined based on the queen criteria. As illustrated in Figure 8, for the variables RTC and major road lengths, travel density, residential population and land area encompassing each LGA, the multivariate Moran Scatterplot relates the values for each variable at a location to the average RTC for neighbouring locations. Figure 9 shows the corresponding empirical reference distribution for the statistics under spatial randomness, constructed from 999 random permutaions. This suggests that each of the observed corresponding values of -0.236; 0.280; 0.242 and -0.333 is highly significant and not compatible with the notion of spatial randomness. The existence of a freeway link crossing a spatial unit, traffic generated within each spatial unit, residential population and area of administration encompassing each LGA, will lead to reduction in the number of RTC; higher RTC; more RTC and a decrease in RTC respectively. However, the position of the latter indicates the existence of other inhibiting factors such as spatial heterogeneity.

These results give a clear indication that explanatory variables, namely, major road lengths, travel density, residential population and area of administration, are significant issues to be considered in the policy design for RTC measures of intervention in any geographical region.

Figure 8: Generalised Moran scatterplot for major road length, travel density, population and area using the queen contiguity weights matrices.

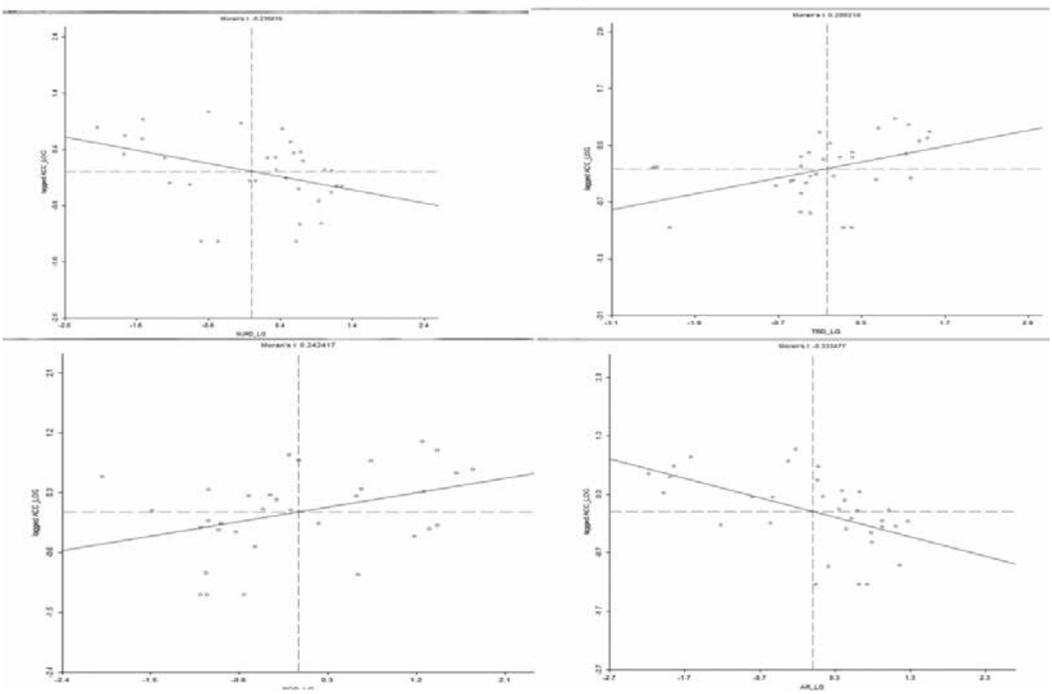
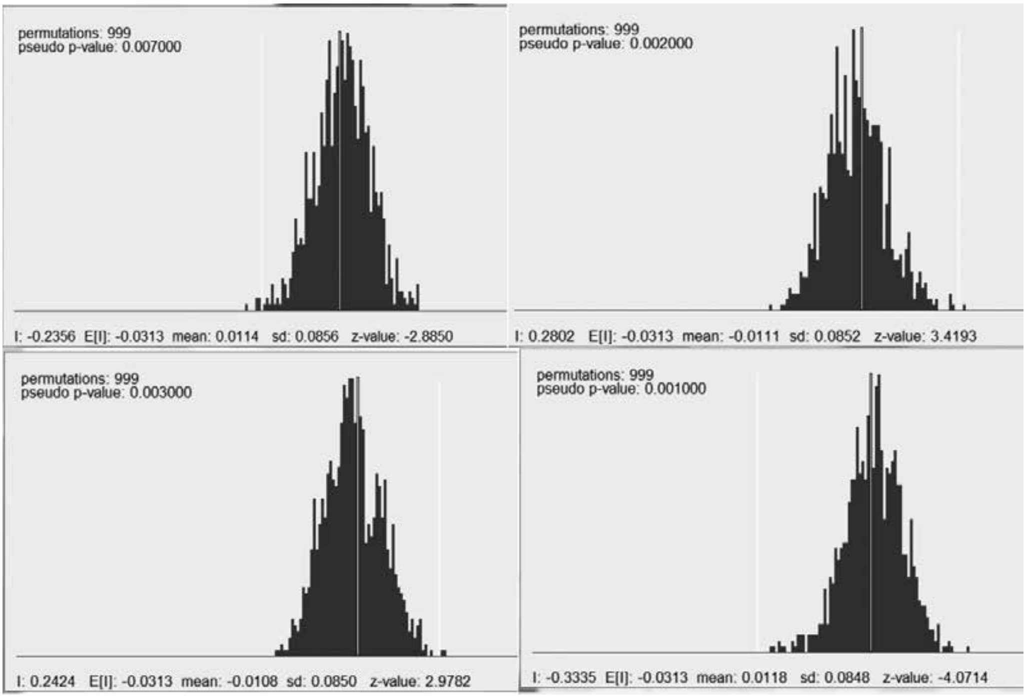


Figure 9: Empirical reference distribution for major road length, travel density, population and area using the queen contiguity weights matrices.



Conclusion and Recommendation

RTC are best managed within small geographical regions and measures for intervention will yield significant results, only when the remedial measures are not administered to the spatial units (LGA) in isolation. A good account of neighbourhood characteristics will identify spatial units, that is, localities within a geographical area that need to be treated simultaneously on the same scale, and those that need not be considered for intervention at a particular point in time. Also, based on an understanding of the linear association that exists amongst variables, governments could be better informed on factors that could be responsible for RTC and thus be scientifically guided to intervene appropriately.

This study concludes that spillover effects do exist in RTC within spatial units across geographical regions. As such, neighbourhood characteristics cannot be ignored when planning for intervention. Apparently, there is a need to incorporate spatial analysis with existing strategies. Therefore, policy design and decision-making at local and global levels need to be reviewed to include neighbourhood characteristics. This approach will help to promote a maximum remedial effect on RTC at local levels, invariably creating a significant impact on overall reduction in the number of people injured or killed on the world's roads across the globe. These results should enable the orientation of safety and injury prevention policies targeted towards reducing the frequencies of RTC.

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