Understanding the spatial patterns of tanker accidents in Nigeria using geographically weighted regression

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Abstract: Road traffic accidents involving tankers are important causes of death and injury in Nigeria. This study examined spatial patterns and possible determinants of tanker accidents in Nigeria. Secondary data on tanker accidents for the year 2007 to 2010 and other relevant data were sourced from the databases of the Federal Road Safety Commissions of Nigeria and National Bureau of Statistics. The spatial patterns of tanker accidents were mapped using Global and local Moran’s I statistics. The data were also subjected to Ordinary Least Square and Geographically Weighted Regression techniques. Findings indicated that tanker accidents vary by state and also revealed an upward trend in the occurrence of tanker accidents. The local Moran’s I indicate persistent clustering of tanker accidents in two states throughout the study periods. Factors influencing the patterns of tanker accidents in the country were identified. The study recommends strategies for the avoidance of tanker accidents in Nigeria.

Keywords: accidents; spatial; tanker; OLS; GWR; Nigeria.


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1 Introduction

In recent years road traffic accidents involving tankers in Nigeria are unprecedented and alarming. The importance of tanker haulage to the distribution of goods especially refined products such as Premium Motor Spirit (PMS), House-Hold Kerosene (HHK), Automotive Gas Oil (AGO), primary and secondary goods across Nigerian landscape and
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worldwide is well acknowledged in the literature (Filani, 2005; Ubogu et al., 2011; Dong et al., 2013; Cherry and Adelakun, 2012). The rates at which tankers are involved in accidents coupled with associated environmental pollution, injury and human losses in the country (FRSC, 2011) call for concerted efforts by researchers, government and stakeholders at understanding the causes and spatial dimensions of tanker crashes with the aim of proffering strategies towards reducing their occurrence.

Studies in Nigeria have observed that incidence of road traffic accidents and injuries in general are on the increase (Ikporukpo, 2004; Arosanyin et al., 2013; Osayomi, 2013). For instance, between January 2007 and June 2010, about 4076 people were killed and 12,994 injured in 4017 cases of accidents involving tankers in Nigeria (FRSC, 2011). This trend has been attributed to factors such as high reliance on road transportation for the movement of people and freight such as agricultural produce and petroleum products (Ikporukpo, 1995; Ubogu et al., 2011); the collapse of the nation rail transport system; unending and complex oil pipeline interdictions (Anifowose et al., 2011; Anifowose et al., 2012); and poor planning, corruption and inconsistent government policies (Ikporukpo, 1983; Ikporukpo, 1995; Ikporukpo, 2004).

In general, road traffic accidents literature in the country have focused on the spatial pattern, causes, magnitude, safety issues and socio-economic cost of road traffic accidents (Oyemade, 1973; Jegede, 1988; Asogwa, 1992; Osime et al., 2006; Filani and Gbadamosi, 2007; Ipingbemi, 2008; Ipingbemi, 2012; Atubi and Onokala, 2009; Arosanyin et al., 2013; Osayomi, 2013). Conspicuously absent from the literature are studies on explorative analyses of the spatial patterns and determinants of tanker accidents in the country.

Considering the high rate of tanker accidents and the prevailing lack of detailed studies on tanker accidents in Nigeria, it is imperative to analyse among others the trend, spatial patterns and determinants of tanker accidents in the country. Specifically, this study applies a spatial analysis at the state level for the period from 2007 to 2010 with the following objectives: (i) determine the magnitude of tanker accidents, (ii) identify spatial pattern of tanker accidents on yearly basis, and (iii) identify the factors that may be associated with the spatial pattern of accidents between 2007 and 2010 at state level. To achieve these objectives an Exploratory Spatial Data Analysis (ESDA) was conducted using information about factors such as population, household size, number of local government areas, road network and traffic volume at the state level.

The paper is organised as follows: Section 2 is a literature review. Section 3 describes the materials and methods used during the research; and Section 4 presents the results obtained, divided into four subsections. The first shows variation in the occurrences of tanker accidents for study duration 2007 to 2010. In the second, spatial–temporal variations in tanker accidents are examined, and spatial clustering of tanker accident is analysed on yearly basis using ESDA in the third subsection. Possible factors responsible for the spatial pattern of tanker accidents in the country are examined in the fourth subsection. Section 5 discusses the results and identifies some policy implications regarding the efforts needed to reduce the magnitude of tanker accident in Nigeria. Section 6 contains the main conclusion.

2 Literature review

Studies on tanker accidents and resulting fatality, injury, and property damages have a long history. For instance, Braver et al. (1996) examined the effect of roadway geometry,
weather, and other factors on the incidence of fatal large tanker–car accidents. Defiance of traffic-control devices, curves, slippery and roadway conditions were some of the conditions found to be associated with fatal accidents. Hallmark et al. (2009) using logistic regressions identified that tanker accidents were more likely to happen when driver is fatigued, upset, distracted, or unfamiliar with the roadway. Similarly, driver fatigue has been identified as an important factor affecting tanker accidents by Gander et al. (2006), who established that 7.6% of accidents in New Zealand were fatigue-related.

Studies have also examined the relationship between accident rates of tankers and driver characteristics such as driver age, driver medical condition, driving experience and driving hours (Summala and Mikkola, 1994; Kaneko and Jovanis, 1992; Loeb and Clark, 2007). Recently, Shen et al. (2014) examined accidents involving 708 tanker accidents associated with hazardous materials transportation in China between 2004 and 2011, with a view to identifying accident causes, location, types, time of occurrence, hazard class for materials involved, consequences, and the corresponding probability. The study revealed among others that: tanker accidents mainly occurred in eastern and southwest China; predominant accident types were rollover (29.10%), run-off-the-road (16.67%), and rear-end collisions (13.28%), with a high likelihood of a large spill occurring; and about 55.93% of the accidents occurred on freeways and class I roads. Their study also revealed that the month with the highest accident rate was July (12.29%), and most accidents occurred during the early morning (4:00–6:00 a.m.) and midday (10:00 a.m.–12:00 p.m.) hours, 19.63% versus 16.10% human-related errors (73.8%) and vehicle-related defects (19.6%) were found to be the primary reasons for tanker accidents.

Studies have shown significant relationship between elements of weather and road transport accidents (Aguero-Valverde and Jovanis, 2006; Sukhai et al., 2009; Sukhai and Jones, 2013; Dong et al., 2013; Bergel-Hayat et al., 2013). Findings from such studies vary due to the time scale of the analysis and the construction of the weather variables. For instance, increased rainfall has been linked to increase accident frequencies (Shankar et al., 1995; Hermans et al., 2006). Similarly, decrease in road of accidents has been associated with high rainfall (Brijs et al., 2008; Karlaftis and Yannis, 2010). Higher temperatures have also been established to be positively correlated with road accidents (Scott, 1986; Hermans et al., 2006; Brijs et al., 2008; Stipdonk, 2008).

3 Material and methods

3.1 Study area

Nigeria is located in West Africa between latitude 4°–14°N and longitudes 2°–15°E. It has a total area of 923,768 km². The country consists of 36 States and the Federal Capital Territory (Abuja) and it is divided into six geopolitical zones: North Central; North East; North West; South East; South South and South West (Figure 1).

Road transport accounts for over 70% of the movement of goods and persons in the country (Akpongomeh, 2002). Road transport network in Nigeria consists of 32,000 km of Federal highways, 30,500 km of state roads; and 130,000 km of local roads (Road Vision, 2000). The road network in the South-Western and South-Eastern parts of the country is much denser than in the rest of Nigeria due to higher population densities
(Ubogu et al., 2011). An extensive network of two-lane highways and few four-lane, dual carriageway connects major cities, including the 36 state capitals and the federal capital to each other. Detail description of road transportation and road haulage industry in Nigeria is provided by Ubogu et al. (2011).

Figure 1  Map of Nigeria showing six geopolitical divisions

3.2 Data sources and variables

The study used two sources of secondary data. The first data set is on tanker accidents from January 2007 to June 2010 and was extracted from publications of the Federal Road Safety Commission of Nigeria (FRSC, 2011). The study period was selected based on the availability of monthly data on tanker accidents in Nigeria. Accident data collection system by the FRSC is on a sector/state basis and provides the opportunity to consider the 36 States and the Federal Capital Territory (FCT) – Abuja, as traffic zones. The accident data attributes include the total number of accidents recorded, total vehicles involved, number of persons involved, total killed, total persons injured and total casualties resulting from tanker accidents.

The second data set consist of possible factors that may influence the occurrence of road tanker accidents. These data were extracted from the Nigerian annual abstract of statistics published by National Bureau of Statistics (NBS, 2012). The data attributes include population size, number of local government area, road infrastructure, traffic volume represented by number of registered vehicle, driver’s license issued, state area, railway length, average household size, illiteracy level and level of unemployment. These
factors were selected based on review of the relevant literature (Jegede, 1988; Filani and Gbadamosi, 2007; Atubi and Onokala, 2009; Osayomi, 2013).

The total accident data for the study periods was used as the dependent variable while the second set of data served as the independent variables (Table 1). A description of some these variables are as follows:

Population size: Population distribution based on the number of rural and urban settlements are serves as demand centres for tanker transported goods. States with more urban centres are likely to have high population which implies high demand for petroleum and other products transported by tankers. Therefore, highly urbanised states are likely to have a positive correlation with occurrence of tanker accidents. Projected populations for each of the 36 states and the Federal Capital Territory of Nigeria in 2010 were obtained from the NBS (2012). Previous studies have found an association between population and road accidents (Filani and Gbadamosi, 2007; Atubi and Onokala, 2009; Osayomi, 2013).

Road infrastructure: Characteristics of roads such as type, length, width, speed limit, and quality influence the road traffic accidents. Travel distance from major oil depots mostly located in the south western and eastern Nigeria influences human and mechanical causes of road traffic accidents. Two variables were obtained on road infrastructure per state: the lengths of federal government roads and distance from state capital to FCT (Abuja).

Traffic volume: Available literature has shown that road traffic accidents are product of increased use of motor vehicles around the world (Kanchan et al., 2012; Jones et al., 2008; Atubi and Onokala, 2009; Osayomi, 2013). In the absence of reliable traffic volume data, this study used available data on two related variables, the enhanced drivers licences issued per state and registered vehicles, as proxy measures for traffic volume. Previous studies in the country used number of registered vehicles in each state and the Federal Capital Territory (FCT) of Abuja to represent traffic flow in Nigeria (Osayomi, 2013).

Level of development: Household size, employment and level of illiteracy are considered as development variables that either increase or reduce likelihood of occurrence of tanker accidents. The first two variables determine the level of demand and of flow of people, goods, and services, while the third variable determines attitudes of people to traffic flow, thereby increasing the risk of road accidents (Jegede, 1988; Atubi and Onokala, 2009; Osayomi, 2013).

To account for the distribution of tanker accidents, the 12 independent variables were first subjected to multiple regression analysis using the stepwise method to assess collinearity among them (Lee and Schuett, 2014). Five of the variables (Table 1) were found to be significant and were used to compute and compare their influence on spatial pattern of tanker accidents in the country using two explorative spatial data analytical approaches: Ordinary Least Squares (OLS) regression and Geographically Weighted Regression (GWR).

OLS is a linear regression method that estimates the globally constant parameters of the dependent variables by minimising the sum of the squared residuals (Li et al., 2009). OLS are based on the assumption that relationships are static and consistent across a study area (Scott and Janikas, 2010). The use of OLS to model spatial data often shows spatial dependence and spatial heterogeneity (Anselin, 1988; Fotheringham et al., 1997). This violates the assumption of non-dependence in the error term required by the OLS
estimation. However, some robust regression techniques such as spatial regression (e.g. GWR) are available to address the spatial autocorrelation issue associated with OLS (Anselin, 1988; Anselin, 2002).

GWR provides a technique to deal with spatial non-stationarity in multivariate regression (Fotheringham et al., 1997). GWR estimates regression coefficients locally using spatially dependent weights. The weight of data points are determined by their distance from each of a given number of estimation locations (Li et al., 2009; Taiwo and Ahmed, 2015). GWR is becoming a more commonly used technique in spatial analysis. For example, it has been applied to investigate commuting patterns (Lloyd and Shuttleworth, 2005), spatial distribution and determinant of bank branches (Ansong et al., 2015b), voters apathy in presidential election (Taiwo and Ahmed, 2015), spatial inequality in academic achievement (Ansong et al., 2015a), and spatial patterns of fire density (Oliveira et al., 2014). These studies demonstrated that spatial phenomenon can be better analysed by accounting for the spatial effects (local dependence and spatial heterogeneity) using GWR (Li et al., 2009).

Table 1  Data and data sources

<table>
<thead>
<tr>
<th>Variables</th>
<th>Source(s)</th>
<th>Operational definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Tanker accidents</td>
<td>Federal Road Safety Commission 2011</td>
<td>Tanker accidents</td>
</tr>
<tr>
<td>Independent Distance from State capitals to FCT (Abuja)**</td>
<td>National Bureau of Statistics 2012</td>
<td>Distance in kilometres</td>
</tr>
<tr>
<td>Independent Total federal roads per state**</td>
<td>National Bureau of Statistics 2012</td>
<td>Transport infrastructure</td>
</tr>
<tr>
<td>Independent Rail length</td>
<td>National Bureau of Statistics 2013</td>
<td>Transport infrastructure</td>
</tr>
<tr>
<td>Independent State area in km sq</td>
<td>National Bureau of Statistics 2012</td>
<td>Administrative</td>
</tr>
<tr>
<td>Independent Number of local government areas</td>
<td>National Bureau of Statistics 2013</td>
<td>Administrative</td>
</tr>
<tr>
<td>Independent Illegal Tanker parks**</td>
<td>Federal Road Safety Commission 2011</td>
<td>Traffic volume</td>
</tr>
<tr>
<td>Independent Enhanced drivers license per state**</td>
<td>National Bureau of Statistics 2012</td>
<td>Traffic volume</td>
</tr>
<tr>
<td>Independent Household size**</td>
<td>National Bureau of Statistics 2012</td>
<td>Level of development</td>
</tr>
<tr>
<td>Independent Level of illiteracy</td>
<td>National Bureau of Statistics 2012</td>
<td>Level of development</td>
</tr>
<tr>
<td>Independent Level of unemployment</td>
<td>National Bureau of Statistics 2012</td>
<td>Level of development</td>
</tr>
</tbody>
</table>

Note:  
*Population projected at 3.2 growth rate  
** Independent variables used in OLS and GWR models after stepwise regression.
3.3 Data analysis procedure

To map and analyse the data sets, we used ArcGIS 10.3, a Geographic Information System (GIS) software. Tanker accidents data were merged with other data (independent variables) to form a new attribute data set. The merged data were appended to spatially referenced data of the 36 states and FCT boundaries using the ‘Join table’ feature in ArcGIS® software. The linked data were used to classify yearly tanker accidents data (in percentages) into five groups of equal intervals. The classified data were used to generate maps showing spatial pattern of tankers accidents in the country for the study period (2007–2010).

The OLS and GWR results were generated and compared based on AIC. Lower AIC values indicate a better model fit to the data. Model residuals were mapped and subjected to Spatial autocorrelation analysis to determine whether the GWR model accounts for the spatial structure of the dependent variable and if it represents an improvement in relation to OLS, by showing a reduction in the spatial autocorrelation of the residuals evaluated for clustering (Anselin, 1995; Koutsias et al., 2010; Sá et al., 2011; Oliveira et al., 2014).

In addition, both global and local Moran’s I statistics (Anselin, 1995) were used to examined the spatial patterns of tanker accidents in the country. The global Moran’s I identified spatial dependency in tanker accidents by state across the entire country, while the local Moran’s I (Anselin Local Moran’s I) identified clusters of states with either unusually high or low occurrence (clusters and outliers) of tanker accidents for each of the study years (Anselin, 1995).

4 Results

4.1 Descriptive characteristic of tanker accidents

A total of 4016 accidents were recorded between 2007 and June 2010. The distribution of tanker accidents varies during the study period. The highest number of tanker accidents between 2007 and 2009 occurred in 2008 (n = 1229) and it is about 50.61% higher than the total accidents in 2007 (n = 607). The total accidents for the country in 2009 were 1213, about –1.32% lower than accidents recorded in 2008. The increase in tanker accidents figures in 2008 can be ascribed to several factors such as increase in freight rates, weather, road condition, driver health condition and presence/absence of road safety officer on federal roads in the country (FRSC, 2011). Surprisingly, the sum of monthly accidents for the first six months in 2010 (n = 968) exceeded 607 tanker accidents recorded for 2007 and the sum of accidents for the first six months of 2008 (n = 615) and 2009 (n = 607) accidents.

4.2 Spatial–temporal variations in tanker accidents

The spatial patterns of the percentage distribution of total tanker accidents in Nigeria between 2007 and June 2010 are shown in Figure 2. Differences were observed in tanker accidents recorded. Ogun state recorded the highest incidence (12.95%) of tanker accidents during the study years. Other states with similarly high occurrence of tanker accidents included Kogi (07.4%), Nasarawa (6.75%), Kwara (6.57%), Kaduna (5.60%), Ondo (5.33%), Oyo (4.46%) and Federal Capital Territory (4.33%). Nine states: Akwa
Ibom (2.54%), Yobe (2.84%), Cross Rivers (2.86%), Osun (2.96%), Bauchi (3.01%), Plateau (3.24%), Lagos (3.44%), Niger (4.08%) and Benue (4.31%) recorded tanker accidents between 2.5% and 4.31%. Tanker accidents recorded in eight other states ranges from 1% to 1.92%. States in this category are Abia (1.00%), Edo (1.27%), Delta (1.34%), Katsina (1.34%), Kano (1.57%), Enugu (1.72%), Sokoto (1.82%) and Imo (1.92%). Lower numbers of tanker accidents were recorded in 12 states: Zamfara (0.02%), Adamawa (0.1%), Kebbi (0.12%), Taraba (0.12%), Ekiti (0.2%), Bayelsa (0.42%), Borno (0.42%), Jigawa (0.55%), Ebonyi (0.57%), Anambra (0.82%), Rivers (0.9%) and Gombe (0.9%).

**Figure 2** Percentage distribution of tanker accidents from January 2007 to June 2010

The percentage distribution of yearly tanker accidents in Nigeria over the period of study is shown in Figure 3 (A)–3 (D). An examination of the figures shows that Ogun state recorded the highest incidences of tanker accidents throughout the study years. This may be due to the fact that Ogere, a sprawling and the biggest tanker community in Ogun state, is located midway between Lagos and Ibadan along the Lagos-Ibadan expressway (Jegede, 1988). The location of settlements such as Mowe, Ibafo, Deeper Life Camp, the Redeemed Camp along the same expressway, a few kilometres away from Ogere, might have contributed significantly to the high frequency of tanker accidents in Ogun state as most of the accidents occurred between Deeper Life Camp/Redeemed Camp ground and Ogere. States with equally high records of tanker accidents throughout the study years are Kogi, Kwara, Nasarawa, Ondo, and FCT (Abuja). These states with the exception of Ondo are located in North Central part of the country and represent the gateway states from the South West, South East and South-South into North East and North West geopolitical zones. The high rate of tanker accidents recorded in the North Central states of Kogi, Kwara, Nasarawa, and FCT (Abuja) could be explained in terms of high traffic.
flow of tankers through the region whose destinations are states in the North West and North East of the country.

Figure 3 (A)–3 (D) shows a clear North-East and South-South pattern in accidents recorded in the country with states with the least recorded tanker accidents are located in North Eastern and South Eastern parts of the country: Adamawa, Anambra, Kebbi, Bayelsa, Borno, Ebonyi, Gombe, Jigawa, Taraba, Rivers and Zamfara. Ekiti state in the South West also belongs to the category of states with low records of tanker accidents. The distributions of tanker accidents in other states are shown in Figure 3 (A)–3 (D).

**Figure 3** (A) Percentage tanker accidents in 2007, (B) percentage tanker accidents in 2008, (C) percentage tanker accidents in 2009, and (D) percentage tanker accidents in 2010

![Tanker Accidents in 2007](image)

![Tanker Accidents in 2008](image)

![Tanker Accidents in 2009](image)

![Tanker Accidents in 2010](image)

4.3 Spatial clustering of tanker accidents

Results of the global Moran’s I test (Table 2) revealed that the distribution of tanker accidents during the study period (2007–2010) in the country was statistically significantly clustered: \( M(i) = 0.32, \ Z\text{-Score} = 3.4, \ p < 0.01 \). The global Moran’s I results for individual year showed that, with the exception of the 2008 and 2009, tanker accidents exhibited significantly clustered patterns. The clustered patterns in 2007 and 2010 imply that the states with similar number of tanker accidents are contiguous. The
significantly random distribution of tanker accidents in 2008 and 2009 showed that there was no distinct spatial pattern in tanker accidents, that is, near states did not have similar number of tanker accidents compared to states that were farther apart (Table 2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Moran-Index</th>
<th>Expected index</th>
<th>Variance</th>
<th>Z-score</th>
<th>p-value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0.2188</td>
<td>−0.02778</td>
<td>0.009338</td>
<td>2.552172</td>
<td>0.010705</td>
<td>Significant clustering at 5%</td>
</tr>
<tr>
<td>2008</td>
<td>0.107</td>
<td>−0.02778</td>
<td>0.007878</td>
<td>1.517932</td>
<td>0.129032</td>
<td>Significantly random</td>
</tr>
<tr>
<td>2009</td>
<td>0.1135</td>
<td>−0.02778</td>
<td>0.008042</td>
<td>1.575154</td>
<td>0.115221</td>
<td>Significantly random</td>
</tr>
<tr>
<td>2010</td>
<td>0.4247</td>
<td>−0.02778</td>
<td>0.009082</td>
<td>4.74778</td>
<td>0.000002</td>
<td>Significant clustering at 1%</td>
</tr>
<tr>
<td>2007–2010</td>
<td>0.3214</td>
<td>−0.02778</td>
<td>0.008645</td>
<td>3.75582</td>
<td>0.000173</td>
<td>Significant clustering at 1%</td>
</tr>
</tbody>
</table>

Analysis of tanker accidents clusters and outliers using Anselin Local Moran’s I index confirmed that states with high record of tanker accidents clustered together. In 2007, significant clusters (p < 0.05) of tanker accidents occurred in Ogun, Oyo and Kaduna States. Ogun and Oyo States shared boundaries and are located in South West while Kaduna is located in North Central part of Nigeria. Ekiti State was the only outlier state (p > 0.05) with lower tanker accidents (Figure 4 (A)). Statistically significant cluster of tanker accidents in 2008 and 2009 occurred in Nasarawa and Ogun States (Figure 4 (A) and 4 (B)). Oyo and Bayelsa states also had high clusters of tanker accidents, while Ekiti state remained the only outlier state in 2008. Osun state joined Ekiti state in 2009 as outliers states in terms of tanker accidents (Figure 4 (C)). In 2010, significant clusters (p < 0.05) of tanker accidents occurred in six states: Ogun, Lagos, Osun in the southwest region and Nasarawa, Kogi and FCT (Abuja) in the north Central region. Ekiti state remains the only outlier state (p > 0.05) with lower occurrence of tanker accidents (Figure 4 (D)).

Figure 4  (A) Tanker accidents hotspot in 2007, (B) tanker accidents hotspot in 2008, (C) tanker accidents hotspot in 2009, and (D) tanker accidents hotspot in 2010
4.4 Predictors of spatial pattern of tanker accidents

Spatial variation of tanker accidents among the states and FCT (Abuja) may be accounted for by variation in several (independent) factors such as population, state’s size, household size, level of unemployment, number of illegal tanker parks, number of vehicles registered and driver’s licences issued per state. To examine the influences of the variation of independents variables on tanker accidents (dependent variable), both OLS and GWR models were used. The results of the OLS model are shown in Table 3. The OLS model explained 22.4% of the variance in the distribution of tanker accidents (Adjusted $R^2 = 0.224$) and three of five selected explanatory variables: household size, distance to FCT (Abuja) from state capitals and total driver licences issued per states were significantly associated with distribution of tanker accidents during the study years. The values of the Variance Inflation Factor (VIF) for each local determinant showed no signs of strong multi-collinearity. The VIF values range from 1.03 for household size to 1.108 for distance to FCT (Table 3).

The GWR model shows significant improvement over the OLS model with adjusted $R^2$ values reaching 43% (Table 4) to account for spatial variation of tanker accidents. An examination of Akaike Information Criterion (AIC) (Akaike, 1974) scores of both models shows that the GWR model provided a better fit to the data because the AIC score of 426.83 was lower than the AIC score for the OLS model (444.93). The 182.1 points difference between the two AIC scores is well above the generally accepted cut-off of 3 points or greater (Fotheringham et al., 2002; Jiang and Xu, 2014). In addition, the Moran’s I value on residuals of the OLS model reduces from 0.124 to 0.051 for the GWR model, signifying that the GWR model explains better the relationship between the dependent variable and independents variables. The spatial distribution of OLS and GWR residuals is shown in Figure 5 (A) and 5 (B). The range of the residuals of GWR model demonstrates that the explanatory power of the model varies by states.
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Table 3  Results of ordinary least square regression

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std error</th>
<th>t_statistics</th>
<th>p-value</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>−196.075</td>
<td>252.811</td>
<td>−0.776</td>
<td>0.444</td>
<td></td>
</tr>
<tr>
<td>Household size</td>
<td>−37.946</td>
<td>17.403</td>
<td>−2.18</td>
<td>0.037*</td>
<td>1.03</td>
</tr>
<tr>
<td>Distance to FCT</td>
<td>−52.327</td>
<td>16.238</td>
<td>−3.222</td>
<td>0.003*</td>
<td>1.108</td>
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<tr>
<td>Road networks</td>
<td>59.703</td>
<td>23.34</td>
<td>2.558</td>
<td>0.016*</td>
<td>1.093</td>
</tr>
<tr>
<td>Illegal parks</td>
<td>32.638</td>
<td>19.959</td>
<td>1.635</td>
<td>0.112</td>
<td>1.061</td>
</tr>
<tr>
<td>Drivers license</td>
<td>41.292</td>
<td>19.431</td>
<td>2.125</td>
<td>0.042*</td>
<td>1.064</td>
</tr>
<tr>
<td>Moran’s I</td>
<td>0.124</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$R^2$</td>
<td>0.362</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.224</td>
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<tr>
<td>AIC</td>
<td>444.933</td>
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Note:  *p < 0.05, **p < 0.01.

Table 4  Results of geographically weighted regression

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Bandwidth</td>
<td>10.797</td>
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<td></td>
<td></td>
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<td>Residual squares</td>
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<td>Effective number</td>
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<tr>
<td>Sigma</td>
<td>83.988</td>
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<tr>
<td>AIC</td>
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<tr>
<td>$R^2$</td>
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<td>Adjusted $R^2$</td>
<td>0.431</td>
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<td>Moran’s I</td>
<td>0.051 (P = 0.400)</td>
<td></td>
<td></td>
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<td>Household size</td>
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<td>−19.851</td>
<td>−33.582</td>
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<tr>
<td>Distance to FCT (Abuja)</td>
<td>−0.166</td>
<td>−0.146</td>
<td>−0.155</td>
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<tr>
<td>Road networks</td>
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<td>0.0453</td>
<td>0.033</td>
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<td>Illegal parks</td>
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<td>3.007</td>
<td>2.279</td>
<td>0.475</td>
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<td>Driver licences</td>
<td>−0.146</td>
<td>−0.166</td>
<td>−0.156</td>
<td>0.005</td>
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The spatial patterns of the five parameters are shown in Figure 6 (A)–6 (D). Higher values (either positive or negative) indicate that the explanatory variable has a greater influence in predicting variation in tanker accident in the state, whereas lower values indicate that the predictor variable is less influential in that state (Malczewski and Poetz, 2005; Lee and Schuett, 2014). The figures revealed that the influence of the variables in the model varied throughout the states in the country. The GWR results in Table 4 show that the local coefficients of the variables, household size and distance from state capital to Abuja, are negatively associated with the distribution of tanker accidents while length of road networks, Illegal parks and numbers of driver licences issued are positively associated with tanker accidents.
The relationships between household size and spatial pattern of tanker accidents are generally negative. States with high negative values are Lagos, Ogun and Oyo in the South West, while Adamawa, Bauchi, Borno, Gombe, Jigawa, Taraba and Yobe states in the North West and North Central show significant low negative relation between household size and tanker accidents (Figure 6 (A)).

Similar inverse relationship was found between distance from state capitals to Abuja, the Federal Capital Territory (FCT) and distribution of tanker accidents (Figure 6 (B)). Adamawa, Borno, Gombe and Taraba states in North East show high negative values between travel distance to FCT and pattern of tanker accidents. Low negative relationship also exists between distance from state capital to FCT and spatial pattern of tanker accidents in Lagos, Ogun, Osun, Oyo, Kwara, Kebbi and Sokoto State.

Figure 6 (C) and 6 (D) shows that length of road networks and number of illegal tanker parks are positively associated with spatial pattern of tanker accidents in the country during the study period. The two variables are predictive of tanker accidents in the South West and South-South States than in other geopolitical zones.

Figure 6  Spatially varying coefficient of the significant predictors of tanker accidents (A) household size, (B) distance to Abuja from state capitals (FCT), (C) length of road network, (D) illegal tanker parks, and (E) total driver licences issued per state.
Figure 6  Spatially varying coefficient of the significant predictors of tanker accidents (A) household size, (B) distance to Abuja from state capitals (FCT), (C) length of road network, (D) illegal tanker parks, and (E) total driver licences issued per state (continued)

5 Discussion

Understanding spatial patterns and determinants of tanker accidents is an important factor in designing effective intervention programs aimed at addressing the high rate of tanker accidents in Nigeria.

The study revealed an upward trend in the occurrence of tanker accidents between 2007 and June 2010. A marked spatial difference in tanker accidents among the states in the country is also revealed by the study. States in the North West, North East, South East and South South experienced lower accidents rate than states in South West and North Central parts of Nigeria. Ogun state had the highest tanker accidents occurrence throughout the study period while the least tanker accident occurred in Adamawa, Anambra, Borno, Bayelsa, Jigawa, Kebbi, Taraba and Zamfara states. The findings on increasing rate of tanker accidents and its spatial patterns is consistent with previous studies on road traffic accidents in the country (Jegede, 1988; Filani and Gbadamosi, 2007; Osayomi, 2013) and study on tanker accidents in China (Shen et al., 2014).
This study used the global Moran’s I statistic to investigate the spatial patterns of tanker accidents for each year from 2007 to June 2010 and found evidence of cases being spatially autocorrelated. The study also identified states with clusters and outliers of tanker accidents using the Anselin Local Moran’s I. Hotspot maps of tanker accidents obtained from the local Moran’s I indicates persistent clustering in Ogun and Oyo state throughout the study period while few other states, Bayelsa, Kaduna, Kogi, Lagos, Osun and Nasarawa, served as clusters of tanker accidents in different years. The reason for having clusters in these states may be attributed to a number of factors. First of all, these states have high concentration of illegal tanker parks and, therefore, the combination of large number of tankers waiting to load from depot with high level of roadside socio-economic activities that characterised such parks in the country may account for the clustering of accident cases (Jegede, 1988). Secondly, population and household size of these states are high which means that high demand by residence of these states for petroleum and other goods mostly transported by tankers and trucks, attract high flow of tankers to the states, which may also account for clustering of tanker accidents in the states. The outlier state throughout the study period is Ekiti. Osun state also features along with Ekiti state as outliers of tanker accidents in 2009.

The study’s findings also establish that spatial patterns of tanker accidents in Nigeria can be partially explained by five significant variables, namely: distance to FCT (Abuja) from state capital, length of federal roads network, number of tanker parks, total drivers license issued and household size. This implies that other factors that are not considered here like human, mechanical and environmental factors may have some influence on the occurrences of tanker accidents and their spatial distribution in the country. Though studies on patterns and determinants of road traffic accidents in Nigeria have identified road infrastructure and population as significant determinants of spatial pattern of road traffic accidents (Filani and Gbadamosi, 2007; Osayomi, 2013), this study, however, revealed that distance to FCT (Abuja) from state capitals and household size are equally important determinants of tanker accidents in the country.

In this study, OLS and GWR models were considered to fully understand the influence of the identified five factors on spatial patterns of tanker accidents. The OLS model explained the spatial pattern of tanker accidents in Anambra, Borno, Delta, Edo, Kwara, Kano, Nasarawa, Ogun and Rivers states, while patterns of tanker accidents in Anambra, Delta, Edo, Kebbi, Kwara, Kano, Nasarawa, Ogun and Zamfara states were significantly explained by the GWR model. The GWR model generally shows significant improvement over the OLS model in predicting factors influencing the spatial patterns of tanker accidents in the country.

6 Conclusion

This study was conducted to help in the understanding of spatial patterns and determinants of tanker accidents in Nigeria. The study also recommends, based on evidence from literature, that human-related factors also lead to tanker accidents (Summala and Mikkola, 1994; Kaneko and Jovanis, 1992; Loeb and Clark, 2007), that safety measures such as presence of road safety officer, the use of audible warning devices that alert tanker drivers to danger ahead and the use of equipment to detect
Understanding the spatial patterns

blood–alcohol levels in tanker drivers should be implemented to ensure that tanker drivers are fully aware of the danger ahead and to discourage them from driving under the influence of drugs or alcohol.

To stem the high incidence of tanker accidents, highway patrol by the Nigerian police and the Federal Road Safety Commissions by day and night are essential in the light of increasing trend in tanker accidents in the country. Also, regular educational programs should be put in place by the Federal Road Safety Commission of Nigeria and other agencies for tanker drivers on safety issues and respect for other road users (pedestrian, commuters and other light vehicles). However, the effect of such programs may be short-lived without effective enforcement of traffic laws, as observed by Ipingbemi (2008) ‘creation of awareness alone may not reduce road accidents’; therefore, training and retraining of tanker drivers must be backed up by effective enforcement of traffic laws and regulations by the officers of Federal Road Safety Commission and the Nigerian Police Force. Enforcement of punitive measures, such as withdrawal of driver’s licence and vehicles from the road other than just payment of fines by erring tanker drivers and operators should also be instituted and implemented.

It must be considered, however, that the present study has some limitations as well. One source of bias is the period considered in this study, 2007–June 2010. Data were collected on tanker accidents and their determinants on the basis of their availability. This difference in data periods did not affect the results of analysis, due to the fact that the values of these variables were collected on state and monthly basis.

Another limitation of this study is the accuracy of the data; even though data used were sourced from established national institutes (e.g. Federal Road Safety Commission and the NBS), it can be argued that possible errors could occur. For example, the tanker accident rates in some FRSC sectors could have been underreported due to several reasons such as lack of uniform template for compilation of accidents data and lack of adequate staff.

In Nigeria, drivers’ licences and vehicle plate numbers are issued by FRSC in each of the 36 states and the Federal capital territory. It is common in the country to see holders of driver’s licences issued or vehicles registered in states like Lagos, Rivers and FCT (Abuja), widely used in other states. Such practice is possible source of bias for this study, because such data (drivers’ licence and registered vehicles) are overrepresented in some states and underrepresented in states where the vehicles or the driver licences are actually in used on daily basis.

Therefore, further study could include additional variables acquired through detailed surveys to develop a more spatially explicit relationship between tanker accidents and several other independent variables not used in this study, such as daily impact of variation in the environmental factors, and the contribution of human, mechanical and roads quality to tanker accidents in the country. Nevertheless, distance to FCT (Abuja) from state capital, length of federal roads, number of tanker parks, total drivers’ licences issued and household size are believed to contribute substantially to the occurrence of tanker accidents in the country.
References


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