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Risk assessment of petroleum product transportation by road: A framework for regulatory improvement

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ABSTRACT

Accidents involving transportation of petroleum products by road has been associated with high frequency of occurrence and high safety consequences in developing countries. Using Nigeria as case example, we analysed 2318 accidents involving truck tankers from 2007 to 2012 with a tailored risk assessment framework. The result shows 79% of the accidents were caused by human factors, mainly dangerous driving. More than 70% of the accident resulted in loss of containment leading to spills, fires and explosions. 81% of the accidents resulted in either injuries, fatalities or both. Most of the 972 accidents with fatalities recorded 1–5 fatalities with occurrence frequency of 0.89. The analysis ranks geographical regions (states) in order of accident consequences and frequencies to enhance regulatory distribution. About 7 million USD was estimated as the average cost per accident. Estimated costs are significant and should motivate improved policy design.

1. Introduction

Transportation of petroleum products by road truck creates numerous opportunities for hazardous materials to be accidentally released into the environment. Depending on the volume upon Loss of Containment (LOC), chemical properties, sensitivity of host environment and proximity of human presence, such releases have safety and environmental consequences. This is especially a problem in developing countries where often towns and villages are situated very close to major roads serving as key transport corridors thereby increasing accident vulnerability (Fabiano et al., 2002; Anifowose et al., 2011). Two different perspectives are often in conflict in the transportation of petroleum products: While operators are particularly interested in profit, the regulatory agencies are interested in ensuring public and environmental safety. Hence, proper accident investigation practices governed by risk assessment principles among operators and regulators are required in order to understand and prevent severe hazards posed by the dangerous properties of petroleum products transported by road (Lawler, 2005).

Risk assessment of transportation of hazardous materials (such as petroleum products) has attracted research attention during the last 20 years (Yang et al., 2010) especially in the context of safe transportation using pipelines (Dziubiński et al., 2006; Citro and Gagliardi, 2012), railway (Liu et al., 2013; Saat et al., 2014) and road (Verter and Kara, 2001; Fabiano et al., 2002, 2005; Gheorghe, 2006; Lieggio Junior, 2008; Bubbico et al., 2009; Centrone, 2009; Guo and Verma, 2010; Tomasoni et al., 2010; Yang et al., 2010). Within the research conducted on transportation of hazmat on roads three approaches can be distinguished. The first approach is the development of frameworks for improving emergency responses based on road, weather, and traffic factors (Fabiano et al., 2005). The second is based on conducting survey and accident risk analysis from historic data to divulge accident characteristics such as frequency of occurrence, accident consequences, and identification of causal factors (Fabiano et al., 2002; Yang et al., 2010; Shen et al., 2013). The last approach focuses on the development of decision making frameworks aimed at improving choice of truck capacity (Guo and Verma, 2010) and route selection (Verter and Kara, 2001; Fabiano et al., 2002; Volkovas et al., 2005; Lieggio Junior, 2008). However, little attention has been given to developing risk assessment model for decision

Abbreviations: AGO, Automated Gas Oil; DPR, Department of Petroleum Resources; FRSC, Federal Road Safety Commission; HHK, House Hold Kerosene; LOC, Loss of Containment; NEMA, National Emergency Management Agency; NNPC, Nigerian National Petroleum Corporation; NOSDRA, National Oil Spill Detection and Response Agency; PMS, Premium Motor Spirit; PPPRA, Petroleum Products Pricing Regulatory Agency; USDOT, United States Department of Transport.

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making in developing countries where the effectiveness of regulation for accident prevention and emergency preparedness and response is often constrained by limited regulatory resources (Aprioku, 2003).

Moreover, there is a need to have a risk assessment framework that exposes the financial implications of accidents involving petroleum product tankers. This is because due to the small and often fragmented character of petroleum product transport operators in developing countries, regulatory enforcement is often lacking and these companies cling to the perception that adhering to good safety and environmental standards is expensive. Hence, there is a need to uncover the real, and often high, but hidden costs of poor safety standards to operators via risk assessments.

Using the case example of Nigeria, we present a regulatory improvement framework based on the identification of relative accident risk hotspots across states and evaluation of financial consequences of accidents involving petroleum product truck transport using fragmented spatiotemporal data. The framework will provide regulators with the means to effectively prioritize resources when regulating transportation of petroleum products. Similarly, by adding a financial dimension to the risk analysis, regulators can use the framework to prompt strong regulatory incentive for improving hazmat transport.

2. Case example: petroleum product distribution in Nigeria

The downstream subsector of petroleum industry in Nigeria is characterised by a complex assortment of infrastructure and processes including refining, distribution, transportation and retailing of petroleum products. The industry supplies about 40 million litres of petroleum products per day to an estimated 170 million people across 36 states and Abuja (NNPC, 2012) mainly via trucking operations (see Fig. 1). In addition to the government owned retailing company (Nigerian National Petroleum Corporation-Retail), there are 6 Major Marketers and over 10,200 Independent Marketers all involved in transportation and distribution of petroleum products (PPPRA, 2006). In 2012 the Federal Road Safety Commission (FRSC) reported the involvement of over 5000 petroleum product tankers in daily haulage on Nigerian roads, accounting for approximately 95% of the country's petroleum product transport volume moving on the road system.

This transport system has been largely responsible for accidents and disasters that pose risks to human safety and the environment (Dare et al., 2009; BBC, 2012). However, regulatory activities (including accident prevention, preparedness and response) have mainly been constrained due to inadequate funding. For instance, while the FRSC have safety requirements and guidelines for articulated lorry (tankers/trailers) operations in Nigeria that covers registration, licencing and emergency preparedness their operations are not efficient (Oluwadiya et al., 2009; Ambituuni et al., 2014). This calls for enhanced identification of accident hotspots for effective regulatory resource prioritisation and distribution as a risk management strategy. A risk assessment model is therefore required in light of the limited access to good quality data which has often contributed to research limitation in Nigeria (Anifowose et al., 2012; Omodanisi et al., 2014).

The highly articulated, small but politically sensitive nature of truck tanker operators in Nigeria (Majekodunmi, 2013), also typifies a case where a framework is required for integrating accident cost analysis so that regulators can build up a case to enforce good safety and environmental standards and also manage the risk perception of operators.

3. Method

3.1. Data

Data collection was a noticeable challenge for this article as it is for many studies in developing countries. As there is no public data base in Nigeria, 2318 accident reports were obtained from 4

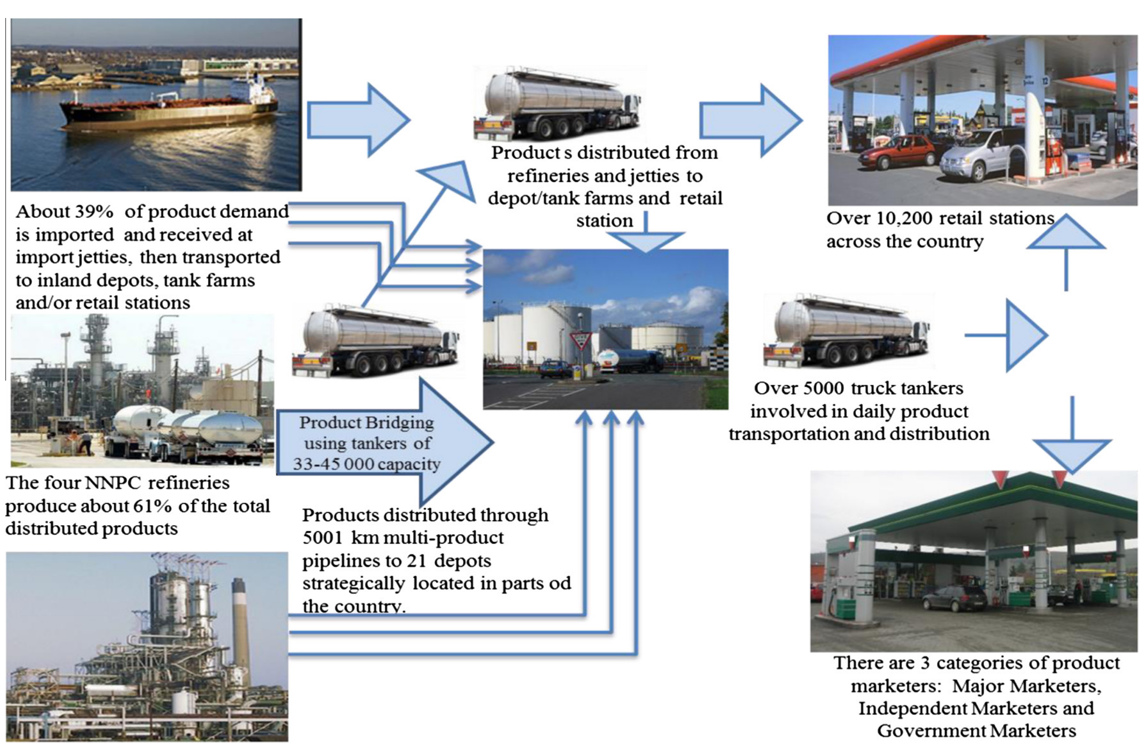


Fig. 1. Downstream structure of Nigerian petroleum industry (Note: pictures used in this diagram were obtained from public domain and used for illustrative purposes only. They do not represent any company's facility).

different sources including: The Department of Petroleum Resources (DPR), Federal Road Safety Commission (FRSC), Nigerian National Petroleum Corporation (NNPC), and National Emergency Management Agency (NEMA). These agencies are duty bound by law to document, investigate and respond to petroleum and road related accidents (Ambituuni et al., 2014). Fortunately, these reports spanned up to 6 years (2007–2012). The details (causes, consequences (fatality/casualties) and quantity of products spill) on each accident report obtained are comprehensive enough to give a contextual view of hazards, accident occurrence and severity. The reports cover accident/incidents involving truck tankers across the 36 Nigerian states and Abuja.

Data representing yearly distribution and sales of petroleum products (Premium Motor Spirit (PMS), House Hold Kerosene (HHK) and Automotive Gas Oil (AGO)) across the states in Nigeria was obtained from NNPC reports, while petroleum product price regime details were obtained from Petroleum Product Pricing Regulatory Agency (PPPRA) (see Table 1 for data and data sources).

3.1.1. Data exploration

The accident reports obtained were first organised and arranged according to year, month and date and time of occurrence. The records were further categorised based on location of occurrence across the states. By tabularising the details of numbers of fatalities, injuries, vehicles involved and type and quantity of products involved within each accident, a contextual accident consequence data was established. States were arranged in alphabetical order and identification numbers 1–37 allocated. The data was then imported into SPSS where it was subjected to various statistical tests within the framework described in Section 3.2.

By summing up the total distributed volume of PMS, HHK and AGO in each of the states and then dividing by 33,000 (a typical truck load in litres), it was possible to estimate the number of truck tanker loads delivering products in each state per year. As the spatial connectivity of the pipeline network in Nigeria has been completely lost following incidents of vandalism (Anifowose et al., 2011) and since there is no retail station directly connected to the pipeline network, transportation of petroleum products to retail stations in Nigeria solely depends on the truck tanker system. This estimation assumes that at a particular point in the lifecycle of the total volume of petroleum product used per year the product was transported using a truck tanker. This data was later used for normalised relative accident frequency computation. Since records of total product distribution by state can only be traced back to 2009, only four years data could be used for this purpose.

In analysing accident financial impact, categories that can be estimated within the data set were first selected. The categories included: fatality, injury, product loss and environmental damage. Other categories such as: clean-up, property damage, evacuation of victims and traffic incident delay costs were excluded due to the limited nature of information in the reports.

Since the risk assessment framework is designed for enhancing regulatory activities, we integrated part of the study discussion with classification of stakeholders and their key interest within the context of transportation and distribution of petroleum product in Nigeria. For example, FRSC is the federal road safety regulator and is interested in road safety across all transport activities (including petroleum product transportation) in Nigeria. Similarly, DPR regulates all petroleum operations including transportation and distribution of products from labelling and packaging to loading and unloading operations (see Fig. 2 for illustrative details). This allowed discussions to be centred on how the framework can enhance regulatory activities using the contextual information on the study location.

Table 1
Data sources.

Data type	Data source
Accident reports across 36 state and Abuja from 2007 to 2012	DPR, NNPC, FRSC and NEMA
Quantity/price of petroleum products consumed (PMS, HHK and AGO) in Nigeria	2012 NNPC sale records and PPPRA reports
Estimated cost of fatality, injury and environmental damage	Battelle (Battelle, 2001)

3.1.2. Data constraints and study limitation

Typical of research in developing countries, this study is constrained by availability and access to good comprehensive quality data. Similar limitation has been reported by Anifowose et al. (2012) and Lawler (2005) where age, format, reliability, access, quantity and quality of data presented constraints to research. Hence, the analysed variables in this study solely depend on variables extracted from the fragmented spatiotemporal data obtained. Working with the available data is in fact a fundamental objective of the framework presented in this study.

Obtaining comprehensive data is especially challenging in the study country due to the secretive nature of the petroleum industry (Amundsen, 2010). For example, the researcher experienced deliberate deletion of some report details from the reports obtained from DPR due to confidentiality claims. Also, all the reports obtained only cover accidents and incidents involving PMS, HHK and AGO. Perhaps, this could be because these three products form the bulk of products used across the country. Hence, with this data, it is not possible to evaluate the contribution of transportation of other petroleum products. Collecting accident reports from 4 different sources also meant that each report had to be cross-referenced using date, time, location of occurrence, and/or registration numbers of vehicles involved with all the reports to sieve out duplications. Therefore, where such clear distinction was not established, the report details were classified based on the only and/or best parameter(s) available. Consequently, accident in this study is defined as an event that occurs when the tanker transporting petroleum product is involved in a collision and/or any event that has led to spill or fire or explosion. Any accident involving the shipment would be considered as an accident regardless of whether there was LOC. This is represented in the event tree in Fig. 3.

There is also the lack of homogeneity of the data used in cost estimation. The dollar values used for estimation of accident cost impact variables was obtained from a study conducted in the US. As there are no established estimates within the Nigerian context, this was the best internationally accepted option we could establish. Certainly, using data from the case country would have been more desirable as it would have given a specific cost analysis related to the risk-cost perception of the case country. Thus, while the study results would not be possible without the availability of these data, limitations of the study can in part be linked to their variegated nature.

3.2. Framework for data analysis

The framework for data analysis in this study consists of two key risk assessment elements, both inspired by the set of data obtained: (a) The risk assessment element consisting of: formulas for identification of accident causal factors; and equations used for the computation of accident frequencies and accident casualty consequence, later used for accident risk quantification in Section 4. (b) Cost impact element comprising formulas for estimation of direct and indirect costs of accidents and computation of the yearly cost impact of accident and losses.

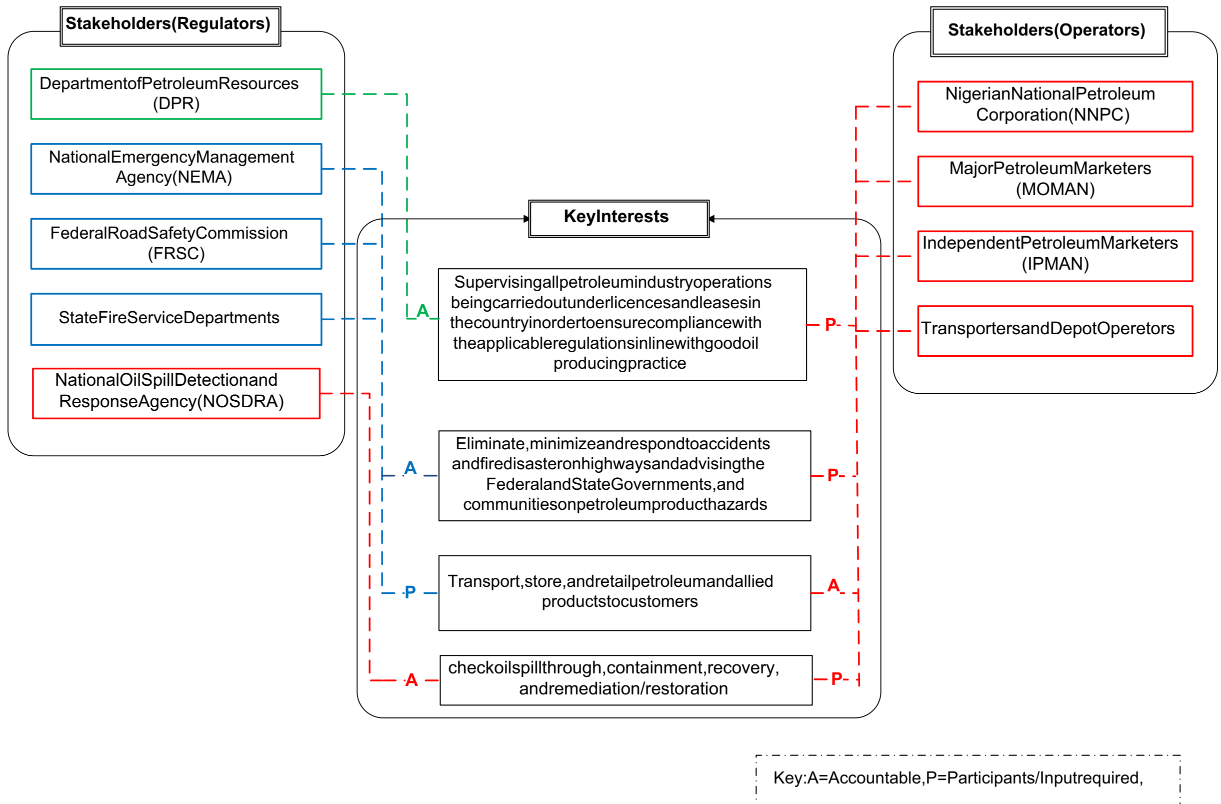


Fig. 2. Interest and classification of the stakeholders involved.

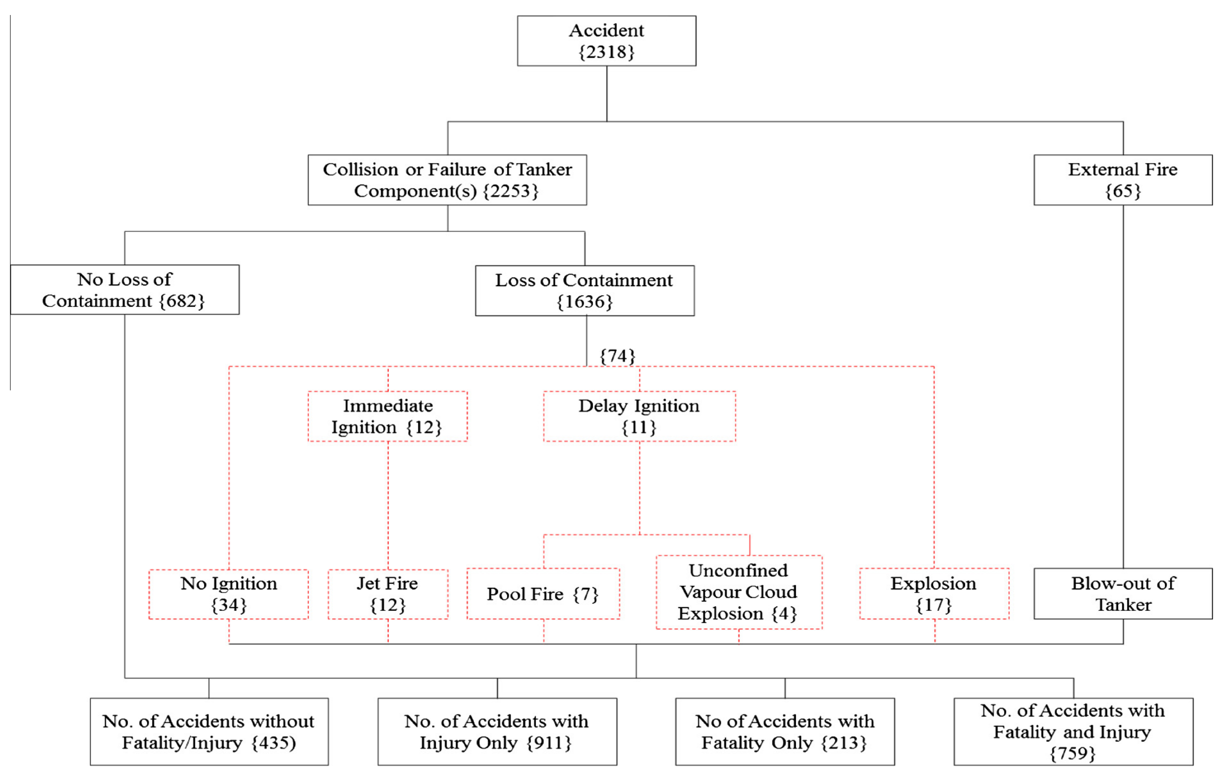


Fig. 3. Accident event tree. Note: Although many of reports clearly stated the quantity of loss product due to accident event, only 74 of the reports identified specific classification of accident phenomena. This was used in the classification highlighted in red dotted lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2.1. Causal factor identification and classification

Based on the reported cause of accident to regulators, we classified accident causal factors into human, non-human and unknown factors. Accident causal factors are factors that contribute to the frequency of accident in a given year.

Total causal factor classification was therefore computed as:

$$\text{Human factor}(Hf) + \text{Non-Human factor}(Nf) + \text{Unknown factor}(Uf) \quad (1a)$$

Hf, *Nf*, and *Uf* values were extracted as:

$$Hf = D_{GD} + T_{PI} + A_{VA} \quad (1b)$$

where D_{GD} is the factor caused by dangerous driving, wrongful overtaking, speed violation, route violation, drink driving and other traffic violations. T_{PI} is accidents caused by third party interference on the road, i.e. human factors not caused by the driver and A_{VA} is armed and violent attack such as armed robbery

$$Nf = Mf + Br + Bw \quad (2)$$

where *Mf*, *Br* and *Bw* are causal factors due to mechanical faults, bad road and bad weather respectively.

3.2.2. Accident frequency

Since n number of accidents were reported in a geographical region (state) j in year y and the total quantity of petroleum product distributed and sold in that state in year y was recorded (as υ_j litres), then the total number of tanker trips k_j to the state can be estimated by diving υ_j by 33,000 l (a typical tanker load). Using the formula of relative frequency, the frequency of accident per trip per year across each state was identified as:

$$\text{Accident frequency per trip}(p) = \frac{n_j}{k_j} \quad (3)$$

where n_j is the number of accident in a state j and k_j the number of trips to that state. The frequency value, however, depends on the assumption that the truck involved in the accident in that state was assigned to deliver product to the state and not just passing by.

3.2.3. Relative accident consequence between states

The data showed various accident locations i through to m across state j (i.e. $i = 1,2,\ldots,m$ accident locations within state j) and casualty consequence q was recorded at each accident location i in state j. By defining $q_{i,j}$ per accident in terms of total numbers of: fatalities ($q_{F,i,j}$) and injuries ($q_{I,i,j}$), it was possible to evaluate the accident casualty consequence i.e.:

$$q_{i,j} = q_{F,i,j} + q_{I,i,j} \quad (4)$$

And total casualty consequence *Qj* per year across state *j* is;

$$Qj = q_{1,j} + q_{2,j} + q_{3,j} + \cdots + q_{m,j} = \sum_{i=1}^{m} q_{i,j} \quad (5)$$

Using Eq. (5) relative accident casualty consequences in different states were computed and compared to determine high risk states.

The relative frequency of an accident having a given number of deaths was calculated using the accident totality statistics. Accordingly, we grouped all accidents (see Section 4.3) based on number of fatalities and calculated the cumulative frequencies using the following equation:

$$p_a = \frac{\sum_{c=a}^{x} N_c}{\sum_{c=1}^{x} N_c}. \quad (6)$$

where N is the number of deaths, P_a is the frequency of an accident with more than N deaths, x represents the total amount of categories or rankings, and N_c is the number of accidents in a given category c. This method was also used by Yang et al. (2010).

3.2.4. Accident and financial loss

Using t as the value representing the corresponding financial consequences associated to accident in location i through to m within state j, we defined t with respect to fatalities ($t_{F,i,j}$), injuries ($t_{I,i,j}$), number of vehicles involved ($t_{V,i,j}$), quantity of product loss ($t_{PI,i,j}$), *etc.* The financial accident consequence at location i in state j was therefore estimated as:

$$t_{i,j} = t_F \cdot q_{F,i,j} + \ldots. \quad (7)$$

Total financial consequence T in state j per year was obtain using Eq. (8)

$$T_j = t_{1,j} + t_{2,j} + t_{3,j} + \cdots + t_{m,j} = \sum_{i=1}^{m} t_{i,j} \quad (8)$$

The total monetary sale value of petroleum product per year in state j is given as T_{psj}. Accident impact on sales in state j was then computed by deducting the total accident financial consequence (T_j) in that state from the total year monetary sale value of petroleum products (T_{psj}) in that state.

4. Results and discussion

4.1. Accident causal factor identification

Table 2 shows a summary of parameters extracted from accident reports. Using the model, it was possible to identify the percentage distribution of the classification of causal factors in Eqs. (1a) and (1b). From Fig. 4 human factors are the most frequent causal factor of accident occurrence. From the 2318 accidents recorded nationally from 2007 to 2012, 1830 (79%) originated from human factors (D_{GD} = 74%, T_{PI} = 3.8% and A_{VA} 1.2%). 429 accidents (19%) originated from nonhuman factors (i.e. *Mf* = 16%, *Br* = 2.77% and *Bw* = 0.23%) while 59 (2%) were recorded as unknown factors. Further analysis at state level (see Fig. 4) also shows human factor as the most frequent causal factor across all states and Abuja. These findings are revealing because contrary to general perception, bad condition of Nigerian roads (Anifowose et al., 2011) and armed robbery and violent attack are not in fact the major contributing factors to accidents. In this category, there were a great variety of causes including: speed violation, dangerous and wrongful overtaking, route violation, and driving under the influence of alcohol and other intoxicants. This is mainly because enforcement is lacking (Oluwadiya et al., 2009).

By identifying the main accident causal factor, regulators have opportunity for formulation and deployment of risk mitigation strategies to address the specific nature of the causal factors. In this case since human factors have been identified as predominant across all states, regulators can design an inclusive and interactive Safety and Environmental Management System (SEMS). The SEMS should target improving culture, behaviour and perception towards personal and process safety specific to the context of the petroleum transport operations and regulatory regime as suggested in Grote (2012).

4.2. Identification of accident hotspots

The 3 × 3 risk matrix shown in Fig. 5 was developed using Eq. (5). States were classified in the matrix based on their relative accident casualty consequence values. The figure illustrates the average relative value for all states within the years under consideration. The distribution of accidents across the nation was also plotted in a map of Nigeria in Fig. 6.

Table 2
Summary by year of parameters extracted from accident reports.

Year	No. of accidents	Fatality	No. injured	No. of persons involved	No. of veh. involved	No. caused by human factors	No. caused by non-human factor	Un-known factor	Quantity of PMS loss (10^3 l)	Quantity of AGO loss (10^3 l)	Quantity of HHK loss (10^3 l)
2007	232	369	741	1639	342	191	37	4	4095.4	510.7	528.4
2008	352	434	1124	2467	518	281	62	9	6712.4	1029.4	893.4
2009	486	434	1345	3038	665	390	82	14	9600.0	1045.5	642.2
2010	415	519	1405	3108	686	317	85	13	7943.4	891.3	908.8
2011	354	374	931	2383	625	251	96	7	7456.5	1153.6	772.9
2012	479	614	1562	3745	997	384	84	11	8328.26	820.37	789.0

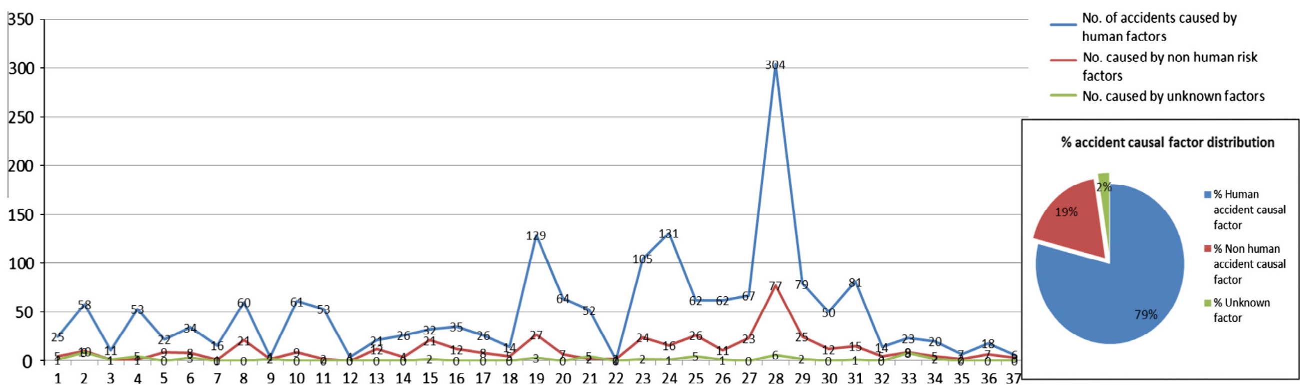
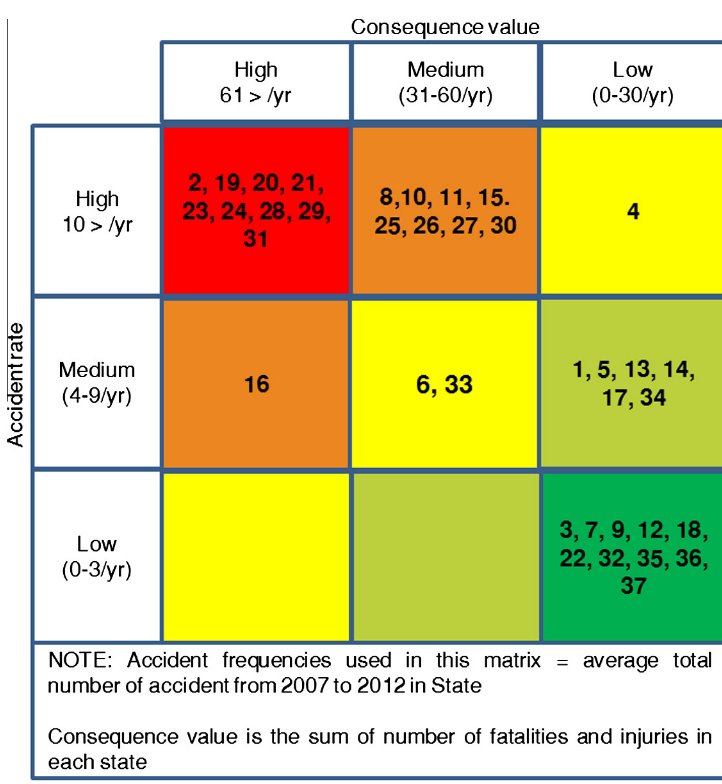


Fig. 4. Showing the distribution of accident figures (2007–2012) across the 36 states and Abuja categorised based on Eqs. (1a), (1b) and (2). Note the % distribution of causal factors with human factor having 79%.



ID. No.	State	Consequence value	avarage accident rate
1	ABIA	27	5
2	ABUJA	66	13
3	ADAMAWA	18	2
4	AKWA-IBOM	26	10
5	ANAMBRA	16	5
6	BAUCHI	41	8
7	BAYALSA	9	3
8	BENUE	47	14
9	BORNO	11	1
10	CROSS RIVERS	36	12
11	DELTA	31	9
12	EBONYI	2	1
13	EDO	12	6
14	EKITI	11	5
15	ENUGU	50	9
16	GOMBE	63	8
17	IMO	17	6
18	JIGAWA	23	3
19	KADUNA	117	27
20	KANO	69	12
21	KATSINA	89	10
22	KEBBI	3	1
23	KOGI	103	22
24	KWARA	115	25
25	LAGOS	55	16
26	NASARAWA	44	12
27	NIGER	44	15
28	OGUN	180	65
29	ONDO	79	18
30	OSUN	58	10
31	OYO	95	16
32	PLATEAU	8	3
33	RIVERS	33	7
34	SOKOTO	25	5
35	TARABA	4	2
36	YOBE	17	4
37	ZAMFARA	7	2

Fig. 5. A 3 × 3 risk matrix showing states ranked based on average yearly accident frequencies and accident casualty consequence.

Not surprising, states with refineries and import jetties such as Kaduna, Delta, and Lagos were identified as high accident risk states, i.e. states with either high accident rate (>10/yr) – high consequence value (>61/yr) or high accident rate (10>/yr) – medium consequence value (31–60/yr). Some of the within this category (e.g. Ogun state, Abuja, Kwara, Kano, Oyo) are positioned along key national transport corridors and have high concentration of economic activities.

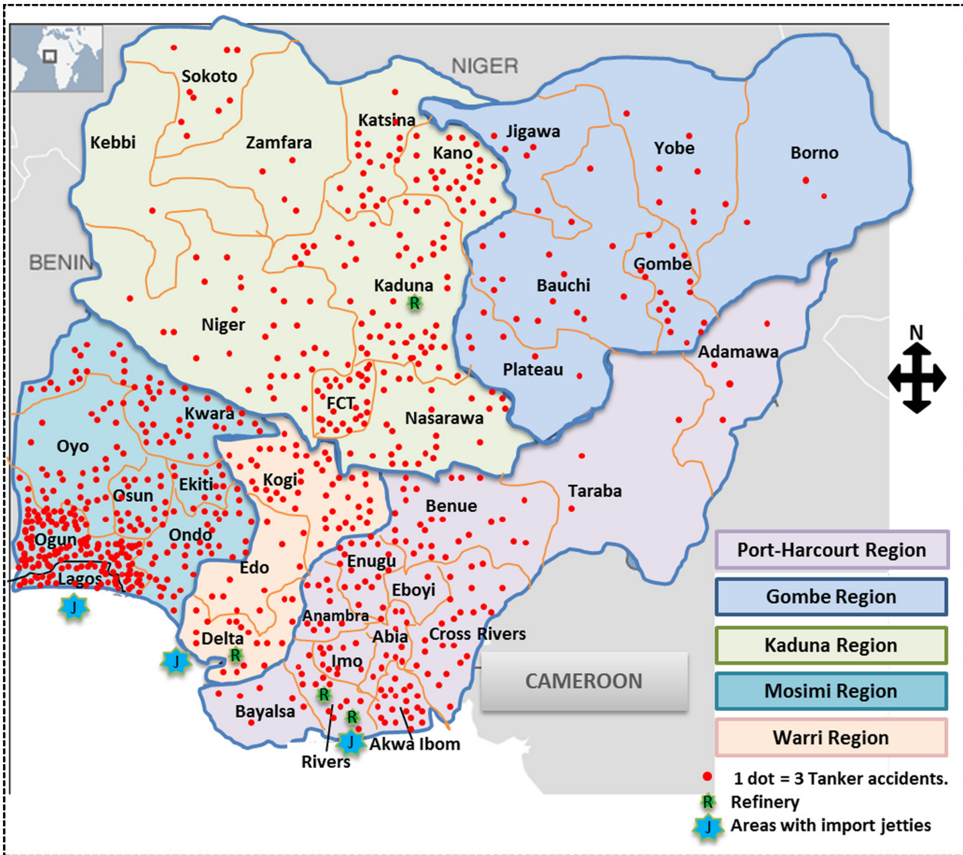


Fig. 6. Map of Nigeria showing distribution of truck tanker accidents (2007–2012) across all states and Abuja within the NNPC petroleum product distribution regions. Note that the dots are not in exact accident positions. (Data representation method adopted from Anifowose et al. (2011).

Eq. (3) was used for accident frequency quantification for evaluating the relationship between accident occurrences and development of a platform for comparison with acceptable risk limits for societal risk, (i.e. the risk or threats from hazard which impact the society) and individual risk, (i.e. how individual personally see risk from a hazard).

In Fig. 7 four maps of Nigeria were developed using ArcGIS based on established accident frequencies for 2009, 2010, 2011 and 2012 for all state. Relative accident frequencies for 2007 and 2008 were not computed because only four years (2009–2012) records of total product distribution by state can be traced. Hence relative accident frequency was computed with 4 years data only. The values were then classified into four limits for each year independent of preceding or succeeding year using the quartile frequency values (Armitage et al., 2008) obtained across the 36 states and Abuja. This classification was used in the map to classify states as: very high, high, medium and low accident frequencies states. The aim here is to have a broad view of accident distribution across each state using normalised data so as to identify patterns that can be used for regulatory purposes. The figure shows consistency in the pattern of accidents, with states such as Ogun, Kwara, Kogi, Oyo, Benue, and Akwa-Ibom maintaining either very high or high accident frequency per truck tanker trip over the four years considered.

By identifying accident risk hotspots, regulatory authorities can channel scarce resources to such locations. Hence with this knowledge, FRSC can invest in traffic management strategies by enhancing the frequency of patrols specifically in such states while also integrating lessons from states with low accident frequencies. Similarly, NEMA, NOSDRA and State Fire Departments can strategically position their stations so as to improve emergency preparedness, accident response and spill clean-up operations. Operators can also design driving training manuals and integrate considerations for these high risk locations.

The time series graphs (in Fig. 8), shows consistently high numbers of accidents in the month of December of the years under consideration. This can be associated with the traveling culture in Nigeria during the Christmas season which results in more demand for petroleum products and an elevated traffic volume. This result can also help in guiding the yearly distribution of regulatory activities.

4.3. Accident consequence

Of the 2318 accidents, 39% resulted in injuries of various degrees, 9% resulted in only fatalities while 33% resulted in both injuries and fatalities. Using Eq. (6), to calculate the cumulative frequency of the number of deaths, accident consequences were categorised based on fatalities i.e. category 1, accidents with 1–5 deaths; category 2, accidents with 6–25 deaths; category 3, accidents with over 25 deaths (Yang et al., 2010). Of the 972 accidents with fatalities, only 3 had fatalities exceeding 25. Notable amongst this category is the Altoada 7th December, 2012 disaster which resulted in the death of 93 people including women and children most of whom were scooping fuel from a leaking overturned tanker. This is not surprising as poverty has been linked to accidents involving petroleum products in Nigeria (Anifowose et al., 2012). Most of the accidents with deaths fall under category 1 with approximate cumulative frequency of 0.89, while category 2 accidents have an approximate frequency of 0.11.

A 2-tailled Kendell's tau non-parametric correlation between: (a) number of accidents and number of fatalities; and (b) number

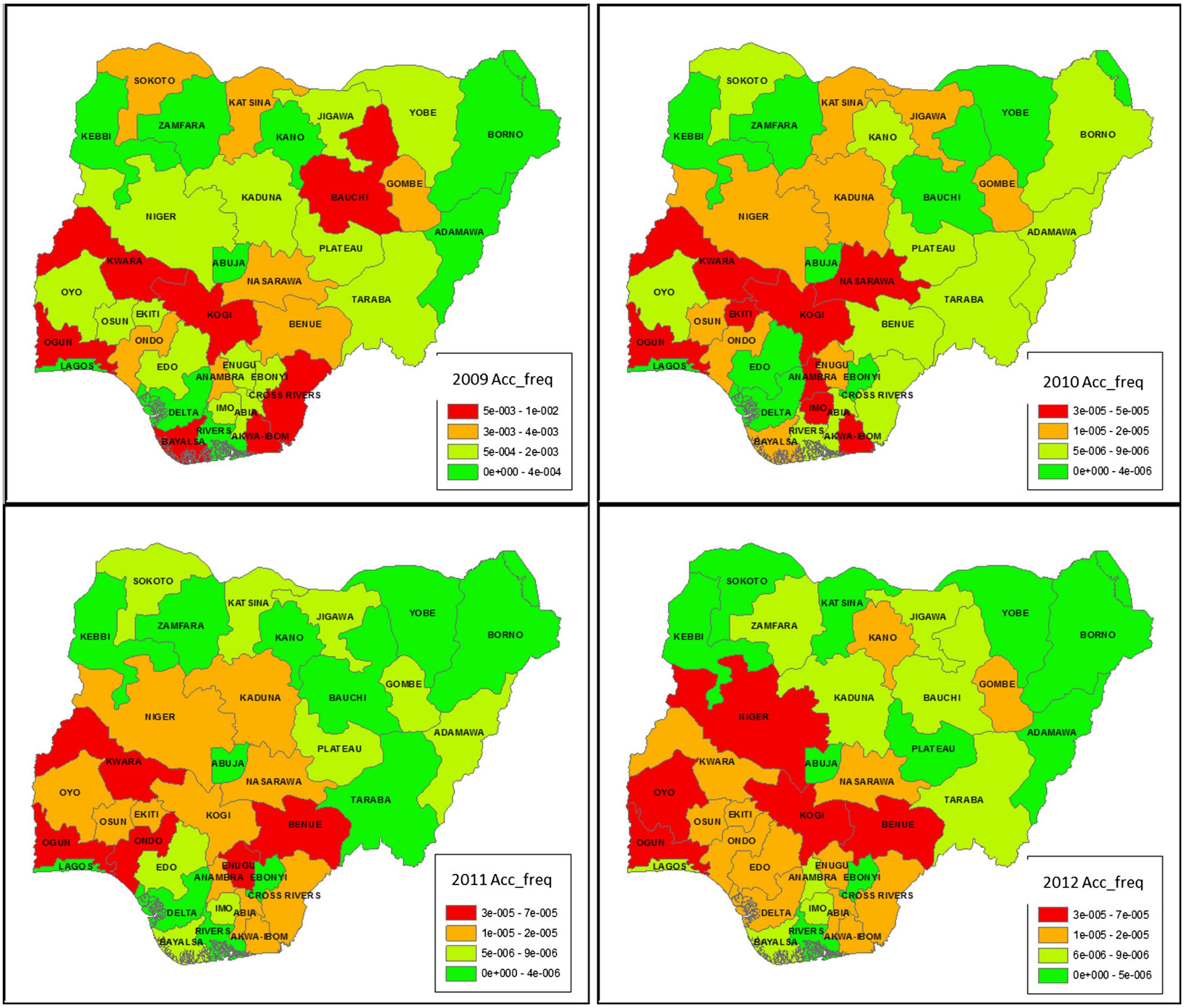


Fig. 7. Accident quartile frequency classification per state per year.

of accidents and number of injuries shows positive correlation between both comparisons (see Fig 9 and 10). As expected, the results (illustrated in Tables 3 and 4) show minimum positive correlation strength between accident rate and fatality of +0.435 and maximum correlation strength of +0.650 in 2011 and 2009 respectively. Similarly, 2008 and 2010 recorded peak correlation strengths between accident figure and injury figure of +0.677 while a minimum strength of +0.532 was recorded in 2011 at 0.01 confidence levels. The strong relationship between accident rate and casualty consequence may be attributed to a poor accident emergency response regime in Nigeria. Accident response is often attended to by federal responders mostly stationed in large cities hours away from most incident locations. This makes communications and response slow and fragmented. To ensure effective accident response and possibly reduce this correlation strength, local capabilities need to be enhanced. Using the strategies discussed in Section 4.2, these capabilities can be enhanced based on priorities for accident hot-spots and within accident prone months.

Also, at least 70% of the accidents resulted in LOC with PMS accounting for 81.55%, AGO 10.07% and HHK 8.38% of the LOC classification by product type. Lack of adherence to quality standards in tuck tanker construction has largely been associated to high percentage of LOCs in accidents (Dare et al., 2009) which increases safety and environmental consequences. This can also in part be attributed to the fact that being a developing country, Nigeria depends largely on imported technology. Hence, where this technology is inaccessible locals make do with substandard local technology. Clearly, broader socio-economic issues need to be addressed in managing accident risk in Nigeria. For example, the recent policy on ban of importation of used vehicles into Nigeria needs to be vigorously implemented as this will promote inflow of companies with regulated standard truck and vehicle manufacturing plants. This, hopefully, will improve the standard of truck tanker construction and maintenance.

4.4. Accident and financial loss

Table 5 compares the total national quantity (by year) of petroleum product sold/distributed and the corresponding quantity loss from truck tanker incidents. From the comparison, it can be seen that 2009 recorded a peak loss value of 11,287,700 litres accounting for 0.12% of the total distributed volume for that year while a minimum loss value of 51,345,000 l (0.05%) was recorded in 2007. The table also shows the corresponding vehicle assets damaged. The extent of damage to the assets was not reported, hence, further cost evaluation was not considered.

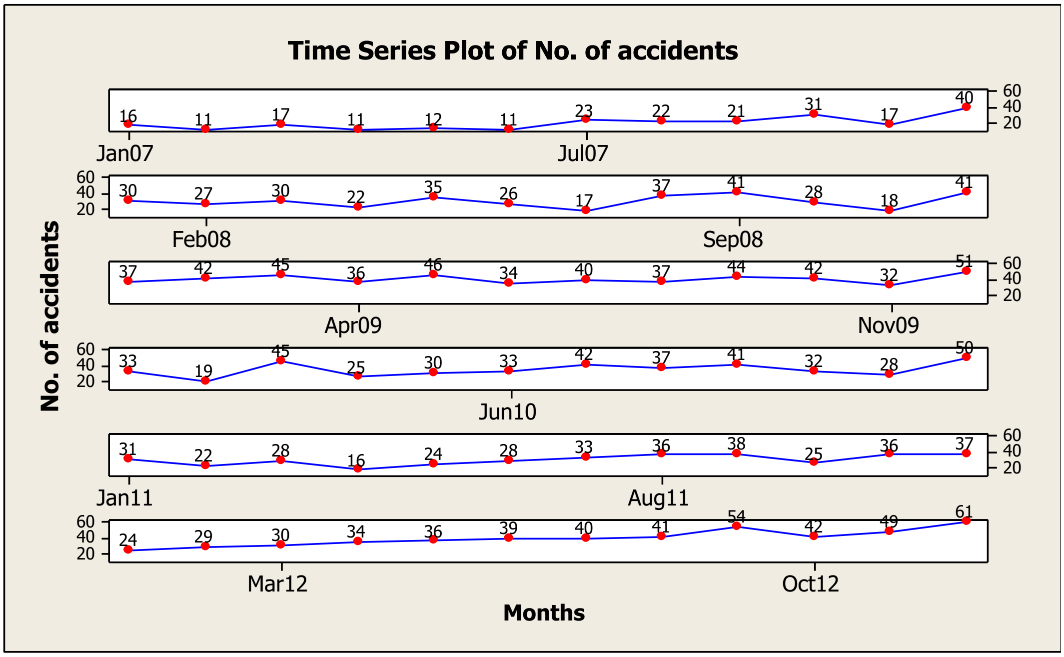


Fig. 8. Time series of monthly accidents.

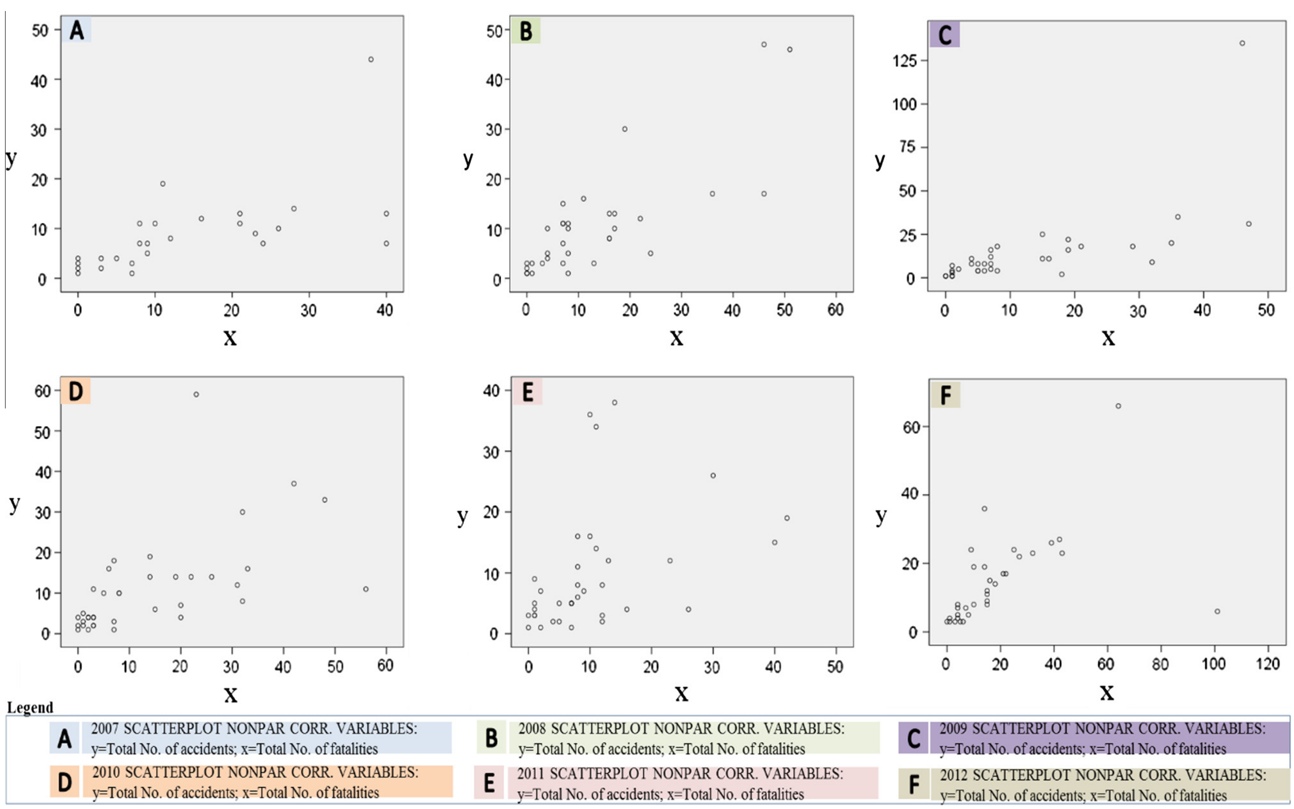


Fig. 9. Scattered plot showing correlation between accident figure and fatality figure across all 36 state and the Abuja.

By multiplying the quantity loss for each product type with the pump price of product as at the year under consideration, an estimated monetary value of the loss in Naira and dollars was obtained as shown in Table 6.

In Table 7, the cost impact of fatalities and injuries were estimated using the data extracted from a study by Battelle (Battelle, 2001). In the study, injuries and deaths were valued to be the amount the United States Department of Transport (USDOT) would be willing to spend to avoid an injury or death. This averaged out to be $200,000 to avoid an injury and $2,800,000 to avoid a fatality. Similarly, the study estimated that for a typical full tanker spill of 33,000 l (8000 gl), $7000 of environmental damage would be

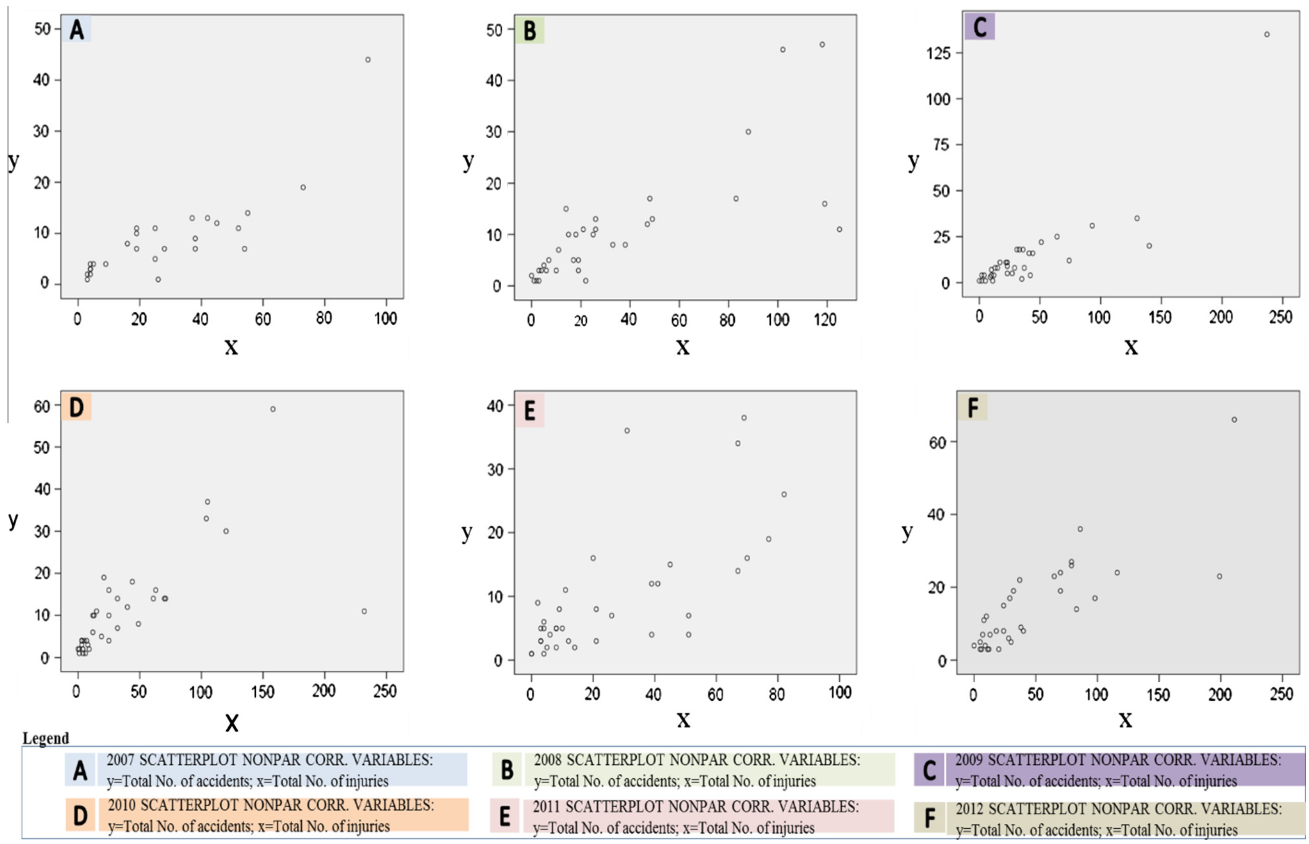


Fig. 10. Scattered plot showing correlation between accident figure and injury figure across all 36 state and Abuja.

Table 3
Correlation coefficient of 2 tailed Kendall's tau nonparametric between accident figure and fatality figure (2007–2012).

	2007	2008	2009	2010	2011	2012
Correlation coefficient (accident fig. vs fatality fig)	0.595[a]	0.606[a]	0.650[a]	0.539[a]	0.435[a]	0.621[a]
No. of state data input	$N = 26$	$N = 33$	$N = 34$	$N = 37$	$N = 36$	$N = 33$

[a] Correlation is significant at the 0.01 level (2-tailed).

Table 4
Correlation coefficient of 2 tailed Kendall's tau nonparametric between accident figure and injury figure (2007–2012).

	2007	2008	2009	2010	2011	2012
Correlation coefficient (accident fig. vs injury fig)	0.669[a]	0.677[a]	0.659[a]	0.677[a]	0.532[a]	0.636[a]
No. of state data input	$N = 26$	$N = 33$	$N = 34$	$N = 37$	$N = 36$	$N = 33$

[a] Correlation is significant at the 0.01 level (2-tailed).

incurred. The study, however, considered the dollar value as at 1996 and the cost of environmental damage was evaluated after an assumption that the spill was cleaned up. Hence, for this study, the extrapolated 2014 dollar value was used. From the analysed accident reports, it is unclear whether spills were cleaned up. Therefore, for the purpose of simplicity, similar assumption was made on spill clean-up and the extrapolated 2014 dollar value for environmental damage was also adopted.

From Tables 6 and 7, the accident cost impact categories considered, (i.e. fatality, injury, environmental damage and product loss) cost transport operators in the downstream sector of the Nigerian

Table 5
Percentage (%) product loss and property damage.

Year	Product sale/ distribution per year (PMS, HHK and AGO) (10^3 l)	Recorded product loss due to truck accident. (10^3 l) (PMS, HHK, AGO)	% Loss	Damaged assets (No. of vehicles)
2007	10111166.2	5134.5	0.05	342
2008	10429768.43	8635.2	0.08	518
2009	9423715.55	11287.7	0.12	665
2010	13423297.54	9743.5	0.07	686
2011	12662114.38	9383	0.07	625
2012	12527533.79	9937.63	0.08	997

economy an approximate sum of $16.32b US dollars from 2007 to 2012. Notably, of the total evaluated amount, fatalities account for $13.63b.

Further evaluation also shows that the downstream sector losses are on average $2.72b per year on accidents, with each accident costing an average value of $7,040,001. This has negative investment implications to the estimated $106.7b (Okulaja, 2013) economic value of the downstream sector. The amount could be even more if other direct cost variables such as clean-up cost, property damage, cost of evacuation of victims, and traffic incident delay cost or indirect cost variables such as: cost of litigation and persecution, fines, reputational damage, increase in insurance premium, etc. were considered.

Taking these observations into consideration, it should be noted that we integrated cost analysis results in the context of establishing a general estimate or bound on the financial impact of this problem rather than a precise valuation. Clearly, in Nigeria, accident cost is not as high as estimated based on U.S. data and this perhaps could be the reason many transport company pay less

Table 6
Cost estimation of product loss @ $1 = N150.

	2007			2008			2009		
	Pump price (N)	Product loss	Cost implication (N)	Pump price (N)	Product loss	Cost implication (N)	Pump price (N)	Product loss	Cost implication (N)
PMS	65	4095400	266,201,000	70	6,712,400	469,868,000	65	9,600,000	624,000,000
HHK	50	528,400	26,420,000	50	893,400	44,670,000	50	642,200	32,110,000
AGO	60	510,700	30,642,000	150	1,029,400	154,410,000	150	1,045,500	156,825,000
	Total (N)		323,263,000			668,948,000			812,935,000
	Total ($)		2,155,087			4,459,653			5,419,567
	2010			2011			2012		
PMS	65	7,943,400	516,321,000	65	7,456,500	484,672,500	97	8,328,258	807,841,026
HHK	50	908,800	45,440,000	50	772,900	38,645,000	50	789,000	39,450,000
AGO	150	891,300	133,695,000	150	1,153,600	173,040,000	150	820,370	123,055,500
	Total (N)		695,456,000			696,357,500			970,346,526
	Total ($)		4,636,373			4,642,383			6,468,977

Table 7
Accident cost impact estimation. Note: the dollar value used = extrapolated dollar value in 2014. Where $1 ≈ N84.58 in 1996 and $1 ≈ N150 in 2014.

Year	Fatality	Estimate cost impact ($)	Injury	Estimated cost impact ($)	Quantity loss	Environmental damage cost impact ($)
2007	369	1,832,347,728	741	262,827,513	5,134,500	13,648,985.02
2008	434	2,155,119,008	1124	398,674,932	8,635,200	22,954,857.42
2009	434	2,155,119,008	1345	477,062,085	11,287,700	30,005,969.07
2010	519	2,577,204,528	1405	498,343,665	9,743,500	25,901,039.15
2011	374	1,857,176,288	931	330,219,183	9,383,000	24,942,725.95
2012	614	3,048,947,168	1562	554,030,466	9,937,630	26,417,092.8
Total cost		13,625,913,728		2,521,157,844		143,870,669.4

attention to human safety and the environment in their operations. If the cost here was applicable to the Nigerian system, the companies will have strong incentives to adhere to good safety measures. Therefore, by using this model regulators can make a systematic attempt to benchmark the financial implications of the problem based on the best available data. Hence, meaningful policy inferences can be derived for risk management purposes.

5. Conclusion

A framework for reducing accidents by improving regulation of transportation of petroleum products by road was presented using a set of disparate spatiotemporal data obtained from several sources in Nigeria. The framework provides contextual understanding of accidents which can be used to improve decisions on distribution of regulatory resources across geographical locations.

Of the 2318 accidents analysed, over 75% were caused by human factors associated to dangerous driving. Regulatory effort, therefore, need to concentrate on limiting human accident causal factors. Using the method of computing accident frequencies and consequences per trip-yr to a geographical location(s), and time series analysis, regulators can identify accident prone locations and likely accident disposed periods so as to expand their presence and improve their effectiveness in light of limited regulatory resources. The accident risk assessment conducted also estimated the dollar value of accidents using established cost of fatality, injury, product loss and environmental damage. On average, it was estimated that the average value of a single accident cost over 7 million USD. The cost dimension can also be used as motivation for policy development aimed at improving the risk perception of operators.

Although the study showed how risk assessment can be conducted using fragmented data, such data has clearly constrained the depth of some elements of analysis. Hence, we recommended that the stakeholders identified in this study should create a joint accident database to support the quality of future research.

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