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Article

GIS-Based Spatial Analysis of Accident Hotspots: A Nigerian Case Study

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Abstract: This study identified high-risk locations (hotspots), using geographic information systems (GIS) and spatial analysis. Five years of accident data (2013-2017) for the Lokoja-Abuja-Kaduna highway in Nigeria were used. Accident concentration analysis was carried out using the mean center analysis and Kernel density estimation method. These locations were further verified using Moran's I Statistics (Spatial Autocorrelation) to determine their clustering with statistical significance. Fishnet polygon and Network spatial weight matrix approaches of Getis-Ord Gi* statistic for hotspot analysis were used for the hotspot analysis. Hotspots exist for 2013, 2014, and 2017 with a significance level between 95% - 99%. However, no hotspots exist for 2014 and 2015 since the pattern is random. The spatial autocorrelation analysis of the overall accident locations with a z-score = 0.0575, p-value = 0.9542, and Moran's I statistic = -0.0089 showed that the distribution of accidents on the study route is random. Thus, preventive measures for hotspot locations should be based on a yearly hotspot analysis. The average daily traffic values of 31,270 and 16,303 were obtained for the Northbound and Southbound directions of the Abaji-Abuja section. The results show that hotspot locations with high confidence levels are at points where there are geometric features.

Keywords: accidents; geographic information system; highway; hotspots; identification

1. Introduction

Globally, the transportation challenges faced by various nations have significantly increased. This increase has necessitated searching for methods that ensure efficient, safe, feasible, and faster means of transportation [1]. Transportation is vital to both economic success and the quality of life in urban and rural areas. However, the growth of city populations, transportation infrastructure, and the corresponding distance travelled have generated adverse effects, such as congestion, air pollution, noise pollution, and motor vehicle collisions. An accident is an unpalatable damage that occurs suddenly without knowing. Road accidents have been a menace to the safety of families and are associated with many problems that need to be treated individually, where road, human, vehicle, and environmental factors play roles; before, during, and after an incident [2]. Road traffic accidents happen when a vehicle collides with another vehicle, pedestrian, animal, road debris, or another stationary object, such as a tree or a utility pole [3].

The hotspot refers to a location along the road that is regarded as a high-risk location for vehicle collisions. Elvik [4] gave a conceptual meaning of hotspot road section as any section that contains a more expected number of accidents than other corresponding sections due to peculiar hazard factors prevailing at the section. He further outlined seven criteria of a modern hotspot identification method as: (a) identification of hazardous road locations from population of sites, (b) avoidance of sliding window method in hazardous road locations identification, (c) use of Empirical Bayes (EB) method in hazardous road location identification based on expected number of accident at a particular site, (d) In a population of sites, hazardous road locations should be identified as the upper limit in EB distribution estimation, (e) a short period (3-5years) of data is appropriate for identification of hazardous locations and development of accident prediction model, (f) on condition that the EB-estimates of expected number of accident by severity for a particular site can be determined, accident severity can be taken into account when determining hazardous road locations, and (g) Particular types of accidents can be look into when determining hazardous road locations, on the condition that EB-estimates of the expected number of accidents of the specific type can be acquired on the particular site. Hotspot programs are planned to reduce the collision risk in areas by improving the physical conditions or management [5]. According to [6], the hotspot is the number of personal injury accidents occurring in a 100 m grid square or 100 m length in three years on a particular road class. Therefore, if 20 accidents are recorded for three years on a 100 m road length, the area is deemed a high-risk site. Overgaard Madsen [7] gave four criteria that a definition of hotspot location must be satisfied as: (a) random fluctuations in the number of accidents should be controlled, (b) factors responsible for having an impact on road safety should be considered, (c) sites with an overestimation of fatal and severe injury accidents should be identified, and (d) locations at which local hazard factor associated with road design and traffic control made a considerable contribution to accident occurrences should be determined. These highway network spots are targeted at an all-inclusive safety program by traffic officials. The most prevalent challenges that traffic officials' faces are where and how to enforce preventive measures and provisions to maximize traffic safety [8].

The geographic information system (GIS) is a comprehensive management tool for traffic safety. The system has several benefits: (a) it allows managers to retain a large amount of data that can be easily stored, shared, and managed, (b) it enables a platform for data analysis and visualization to examine affinity between data, and (c) it can provide graphical and non-graphical results. Due to the spatially distributed nature of accidents, the use of GIS provides the capability to store, update, retrieve, compare, and spatially display data [9]. GIS allows hotspot maps to be electronically generated from a well-designed accident database and can produce high-accident rankings based on the total accidents occurring or accident rates. The advances in GIS and remote sensing can be effective in accident analysis. In addition to promoting the linkage between various types of data and maps, GIS can visually display the results of analyses, thus enabling sophisticated analysis and quick decision-making. Also, these tools would make the analysis less time-consuming and less tedious. Thus, GIS offers a platform to maintain and update the accident record database, which can be used for further analysis [10]. Hence, the need to apply these tools in analyzing the hotspots along the Lokoja-Abuja-Kaduna highway is necessary.

All efforts to reduce the effects of traffic collisions are critical. Amidst these, identifying hotspots and considering likely causes have been studied extensively. Hotspot identification is usually the first step in a safety improvement program. In many safety improvements programs, sites are ranked according to their conditions and a subset of sites are then selected as the highest accident risk sites. Since budgets are limited, priority is given to these high-risk locations to implement precautionary measures [11].

The Lokoja-Abuja-Kaduna highway is a major federal highway that connects the North West and North Central to the Southwest zone of Nigeria. Especially in the festive periods, vehicles plying the route have increased dramatically compared to other periods. Hence, traffic accidents have become more common. Thus, it becomes necessary to reduce these accidents by carrying out a comprehensive analysis and taking precautions. This study aims to identify the hotspots along the Lokoja-Abuja-Kaduna highway, in Nigeria using GIS. The study involved producing hotspot maps, classifying the hotspots based on density and confidence level, and examining their roadway geometric features to determine how, what, and where accident countermeasures can be applied.

The remaining sections of the paper are organized as follows. Section 2 presents a review of the spatial analysis methods of accident hotspots. Section 3 describes the data collection and GIS analysis. Sections 4 and 5 present the results and discussion, respectively. The conclusions are presented in Section 6.

2. Review of Spatial Analysis Methods

Spatial data and analysis are some of the highly essential information for traffic accident analysis. GIS-aided spatial data and spatial analysis provide factual information to analysts about dangerous locations, hotspots, and warm spots. With GIS, the analyst can combine accident and highway data, geocode the accident data and locations, calculate the frequency and rate of accidents, and select a variable for stratification to calculate the mean and standard deviation of accident rates [12]. Identification of safety defective locations with GIS-aided spatial analysis will help to reduce traffic accidents. However, the success of these analyses relies solely on the precision, reliability, and all-inclusiveness of the traffic accident data. Countries have no agreement on items included in the traffic accident reports [13]. Aderinlewo and Afolayan [14] developed road accident prediction models for Akure-Owo highway, Ondo State, Nigeria, based on field survey and the Nigerian Federal Road Safety Commission (FRSC) accident reports. They found that the FRSC report forms were not detailed enough about accident occurrences at the locations along the study route. There are discrepancies among the accident data of different years regarding the parameters included in the report.

Since 1990, various researchers have studied GIS technologies and their applications in the spatial pattern of accident analysis. These cut across spatial accident analysis models, spatial query, pattern analysis, proximity analysis, and segment and intersection analysis. The effects of various factors on safety performance are examined through traffic safety studies. These include the influence of geometric features of road design, environmental factors (e.g., weather conditions), and geographic conditions on accident occurrences [8,15-17].

Easa and Chan [18] present various GIS applications in urban planning and development, including transportation, public utilities, remote sensing, trends in spatial databases, linear referencing systems, demographic forecasting, stormwater and waste management, and environmental assessment of air quality. Owusu et al. [19] analyzed a road traffic collision pattern in the Cape Coast Metropolis of Southern Ghana using GIS. Sandhu et al. [20] identified highway hotspots using the Kernel density estimation (KDE) method, where GIS was used to map, visualize and examine accident data. The hotspots were verified using Getis-Ord Gi* (GOG) tool and Global Moran's I statistic to measure the spatial autocorrelation. In a pilot study, [11] determined traffic accident hotspots on the Turkish highway road network by comparing the traditional hotspot detection methods with the spatial statistical methods. The spatial method was susceptible to the accidents that occurred with multiple vehicles. In a further study, [21] used GIS as a management system for accident analysis and statistical analysis to determine accident hotspots in the Afyonkarahisar administrative border in Turkey. They inferred that traffic agencies could retrieve, analyses, and display accident data in a correctly set up GIS system. Olusina and Ajanaku [22] also mapped accident hotspots from primary and secondary data sources. The accident spot severity and venerability were determined based on the weighted severity index using KDE methods. Verma and Khan [23] also identified the most vulnerable accident hotspots along Sagar-Shahgarh districts using a weighted severity index. The cluster analysis was carried out using spatial autocorrelation to ascertain the level of distribution of the hotspots. It was concluded that the research could be a vital tool for stakeholders in the road transportation sector. Sabel et al. [24] used KDE cluster analysis to identify road accident hotspots in Christchurch, New Zealand. Bello [25] also examined a stratified accident analysis in the city of Richardson using kernel densities. In Honolulu, Hawaii, spatial patterns of pedestrian collisions were analyzed by [26] and [27] using the k-means clustering method. Sajed et al. [28] combined accident data, traffic and geometric characteristics to identify hotspots.

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2.1. Comparison of Various Methods of Hotspot Analysis

Considerable advances have been made in hotspots identification on the roads during the last years. This was made possible by GIS and global positioning system (GPS) applications in transportation research. Various methods of hotspots identification have been used in the literature, including global indexes such as GOG, Geary's C, and Global Moran's I (spatial autocorrelation). Also used in the literature are local indices, such as Kriging, Local Anselin Moran's I, KDE, Spatial Analysis along Network (SANET), KDE+, and Spatial Traffic Accident Analysis (STAA). Except for Kriging and KDE, these methods involve testing the statistical significance of accident clusters [29]. The number of events over a unit area at a specified location (i.e., first-order properties) is addressed using KDE in a spatial hotspot analysis of point (point pattern analysis). In contrast, the second-order properties are addressed by Geary's C, GOG, and Moran's I, which deal with the spatial dependence and statistically evaluate the interaction between several events in pairs at a specified area [30]. Kriging is an improved spatial analysis approach primarily used in various fields of research [31,32]. The SANET toolbox is used to overcome the shortcoming of planar spatial analysis for point events that are restricted to linear networks [33]. This toolbox is a spatial network analysis that evaluates the intensities of points on a network and outlines the network sections with high intensities. Compared to the planar spatial analysis method, it is highly efficient for a network with Euclidean distances prone to error [29,33,34]. The STAA method is a hazard-based approach that considers accident severity, frequency, and socioeconomic influences to analyze historical accident data [35]. STAA is a network-defined method comparable to SANET-KDE and KDE+. However, unlike SANET-KDE, STAA does demand the accident points to overlap with the road's centerline. By so doing, the initial coordinates of the accident points are maintained. This method is appropriate for analyzing single and network of roads [29].

The methods used in road traffic accidents cluster analyses are K-function, nearest-neighbor, KDE, dangerousness index (DI), hierarchical clustering (HC), and climbing. The K-function and nearest-neighbor methods provide evidence about the tendency of clustering on a road section but cannot specify the specific part of the section it occurred. Therefore, these methods do not contribute to the clusters' localization within the sections [36]. The actual cluster position within a section or a network can be identified using the KDE and DI methods. The HC method has no mechanism for determining the statistical significance of clusters. It could only recognize the clusters of traffic accidents. The DI method is a particular case of KDE and relies on the "points of measurement". The climbing method can determine the cluster positions but is highly susceptible; implying that a bit of change in the location of road traffic accidents outside a cluster can substantially influence the cluster's importance.

As stated by [21,24,37] and [38] the KDE, cluster analysis and GOG are among the effective and frequently used methods for identifying the actual cluster location (hotspot) within a network or section. The principal merit of the KDE approach is that the bandwidth of the kernel is used to express the uncertainty about the actual accident location. This implies that KDE allows for spreading the risk of an accident [37]. As [38] indicated, KDE is more suitable for visualizing than identifying hotspots. Presently, an inclusive examination of the statistical significance of KDE is lacking in the literature. Network KDE is more efficient for analyzing accidents on 1D linear space (e.g., a road) [39-41]. An extended KDE approach evaluates the probability density function of the event points using the kernel function is KDE+. The + signifies the criticality in selecting significant clusters [42]. Application of the approach has a limitation in that it is very effective for event points along the segments between the intersections only, since many accidents at intersections can surpass the occurrence of hazardous locations at the road segments between the intersections [36,43].

Several studies have used planar spatial analysis methods, such as KDE, Kriging, Local Anselin Moran's I, and GOG for hotspot analysis with global indices, including Global Moran's I and Geary's C. However, only a few studies compared the different

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approaches to hotspot identification. Thus, this paper used the two approaches (fishnet polygon and network spatial weight matrix) to identify hotspot locations in the study area.

In these approaches, the distances between the network features were measured as adopted in the literature, and were not the ordinary Euclidean distances. Also, instead of the bandwidth, the generated network spatial weight matrix, was fed into the GOG statistics.

3. Data Collection and Analysis

3.1. Study Route

The study route is the Lokoja-Abuja-Kaduna highway. It lies between latitudes 07^0 47'N, 09^0 05'N, and 10^0 30'N and longitudes 06^0 45'E, 07^0 32'E, and 07^0 21'E respectively. There are three state capitals connected to the route. Lokoja is located in the Northcentral zone of Nigeria, and it is the capital of Kogi state. Abuja is located in the Northcentral of Nigeria, and it is the headquarters of Nigeria. In contrast, Kaduna is located in the North West of Nigeria, and it is the capital of Kaduna State. The Lokoja to Kaduna highway is a dual carriageway. The section in Lokoja starts at the Lokoja central market intersection and ends at the Abuja intersection for the section in Kaduna. The total length of the study section is 385 km. The accident data for 2013-2017 were obtained from the FRSC.

A preliminary analysis determines the number of accident occurrences at locations along the route in the year under consideration. This step was carried out through the GIS map, where the names of places were indicated along the route. **Figure 1** shows the GIS map for the study area.

The map shows evidence of spatial autocorrelation as most neighboring locations along the route display similar configurations. This spatial relationship is further analyzed through appropriate tests in the next section.

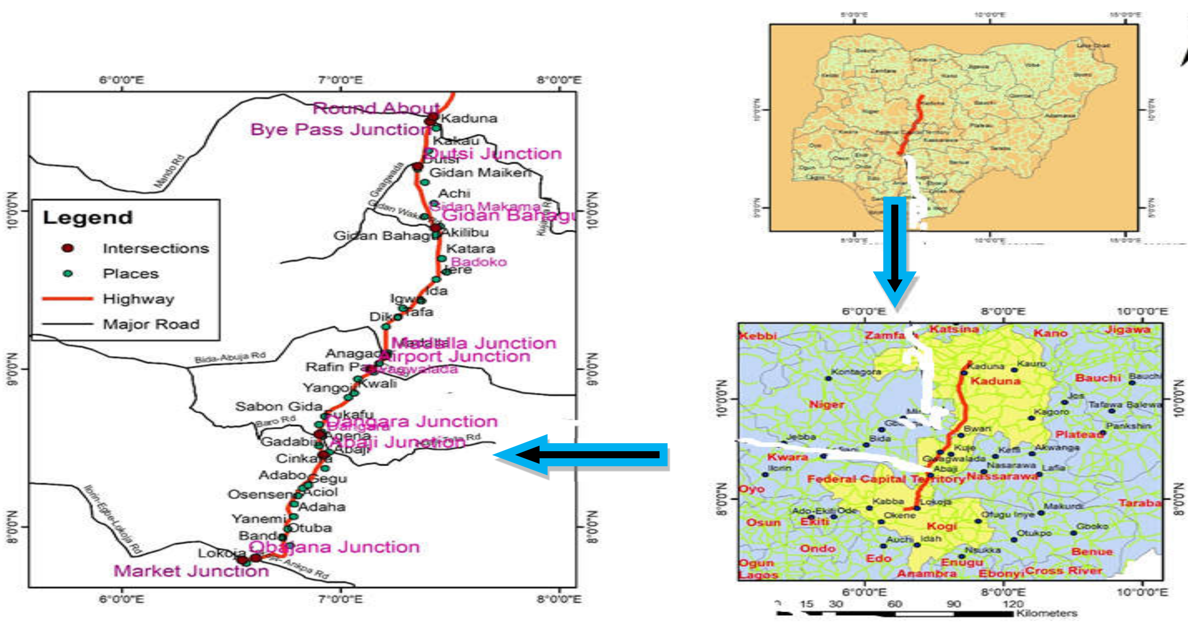

Figure 1. GIS map of the study route.

3.2. Data Collection

A desk study was conducted for the accident data acquired from the FRSC Abuja office. The locations along the study area where accidents had occurred from 2013 to 2017 were extracted and tabulated for further analysis. A reconnaissance survey was carried out on the study highway. The FRSC unit command and accident emergency response (ZEBRA) were contacted for information regarding accident occurrence. Data were acquired from both primary and secondary sources. The primary data source included geometric (coordinates) and attribute data of the accident spots. The field data were collected using Garmin-handled GPS, where the GPS survey was conducted for all the locations of the accident points. The secondary data source included Google earth imagery, accident data from the FRSC, and records of online accident reports. These data aided in identifying accident locations quickly and in quick information gathering. The Google Earth interface covering the study area was imported into the ArcGIS 10.2.1 environment using the Arc2Earth extension tool. Features such as the study route, intersection, U-turns, and intersecting roads were digitized using the Editor.

A traffic counter was installed at the study area to obtain the traffic volumes for the sections with hotspot locations. In addition, a 24-hour count for seven days was carried out, and the average daily traffic (ADT) was obtained for the sections. These data were needed to determine the relationship between the number of accidents and the traffic volume. In addition, the data help to ascertain that the accident that occurred at the hotspot locations was not due to significant traffic exposure.

3.3. GIS-Based Analysis

The causes of accidents from the record of FRSC were summarized on maps, charts, and tables. To validate the accident records from FRSC and identify hotspots along the study route, four different types of analysis executed in ArcGIS were conducted: mean center analysis, KDE, cluster analysis, and hotspot analysis.

Mean center analysis: this method involved measuring the possible geographic mean of the accident locations along the highway network, taking the frequency of accidents at locations as a weight. The weighted mean center algorithm pulls the geographic center value or frequency toward accident locations with higher frequency attributes. The output of this computation can give the analyst an idea of where more accidents are concentrated in the study area. Specifically, the computation was done for each year and displayed in a single window to show any noticeable shift in the mean center.

Kernel density estimation: the kernel density estimation was performed on the data to generate a subjective heat surface of the variation in the values of traffic accidents from high to low. This measure estimates the proportion of the total accidents that can be expected to occur at any given map location.

Cluster analysis: the spatial autocorrelation (Moran’s I) algorithm simultaneously measures both features' locations and features' values. It returns the pattern expressed by the data regarding whether they are clustered, dispersed, or random. Moran's I is an inferential statistical method, which means the analysis results are interpreted within the null hypothesis. The null hypothesis assumes complete spatial randomization. That is, values are randomly distributed among features, reflecting a random spatial process at work. This method was intended to reveal whether the clusters with high or low traffic accident values are statistically significant. Moran's I was referred to as the high or low cluster (Getis Ord. General G) because the values associated with the accident points are not reasonably evenly distributed (as examined using KDE) across the study area. General G statistics are more appropriate for achieving such a distribution, where the local spikes in the values are picked as clusters of high values. Moran's I, however, is suitable for looking at clusters in the dataset because it correlates the values of the features globally with a fixed distance band or the average nearest neighbor and returns the features whether as clustered, dispersed, or randomly distributed. For this analysis, a network spatial weight matrix that chooses 8 nearest neighbors and a distance on a network of 7 Km was generated. The scale of the analysis indicates this being a 385 km stretch road and the separation between accident locations. A smaller neighborhood selection would result in many of the features not having neighbors in the analysis, which will result in outputs that are not representative of the phenomenon in the study route. This is consistent with the recommendations of [33] in the case of bandwidth to cell width. Chainey [44] also inferred that the selection of widths should be as effective as possible to guarantee that visual appeals and spatial patterns do not jeopardize the precision of output results. This analysis was done for the individual years to observe whether there are changes in cluster intensity. The Z-scores for each year were plotted against the corresponding year to create a line chart. The Z-score is a measure of standard deviation for each of the 88 locations. Accident locations with a very low or very high Z-score fall outside the normal distribution and indicate a statistically significant area for analysis.

Hotspot analysis: this analysis was conducted using Fishnet polygon analysis and network spatial weight matrix analysis. The fishnet polygon analysis aggregated accident locations into a fishnet grid. Each grid contained several accident locations that represent the weight of the grid. An optimized cell size of 4.239 km was used as the fishnet polygon mesh size for aggregating incidents. This was considered adequate because each grid contained at least one accident point for the chosen cell size. There were 48 weighted polygons with a weighted mean of 1.8333, a minimum of 1.00, and a maximum of 7.00. An optimized average distance to the 3 nearest neighbors for each fishnet polygon was used for the analysis. The network spatial weight matrix was used to conceptualize the spatial relationship among the accident locations on the highway network. This was input instead of the bandwidth into the GOG statistics in order for the algorithm to respect the peculiar network distance between the highway features. This is similar to conducting the SANET tool used by [29]. The matrix was generated on a network dataset that comprised the highway features and intersections for this analysis. The distances between the features were therefore measured within the network and were not the ordinary Euclidean distances. The matrix created for this analysis had a 9.1% spatial connectivity and used 8 nearest neighbors within the network for the GOG. The output of both approaches was interpreted based on the null hypothesis, whether the data are clustered, dispersed, or random.

4. Results

4.1. Accident Severity, Contributory Causes, and Locations

The data obtained from FRSC were analyzed to identify fatal accidents and injury-only accidents along the study highway. The results of the analysis are shown in **Table 1.** As noted, 4,656 accidents occurred within the study period (2013-2017). The majority of accidents occurred in 2013 where the number of accidents was 1,285. This decreased to 861 accidents in 2014, 815 in 2015, 704 in 2016, and 991 in 2017. In 2013, the fatal accidents represented 40.5% of all fatal accidents recorded during the study period. However, 2015 and 2016 experienced a remarkable decrease in accident fatalities and injuries with 9.5% and 6.8%, respectively. A sudden increase in the number of accidents/fatalities was experienced in 2017 perhaps due to defects in pavement conditions.

The obtained data were analyzed to identify the significant indicators for the specific safety problems at the locations. As noted in **Table 2**, speed violation (SPV) and loss of control (LOC) were the most common accident contributing factors, comprising approximately 27% and 21% of all accidents, respectively. The two leading causes are interwoven, where drivers are liable to lose control of the steering at high speed, resulting in an accident. The third leading cause of accidents is sign light violation (SLV), with 16% of all accidents followed by tyre burst (TBT), approximately 11% of all accidents. Other factors that have not been reported account for less than 10% of the total accident that occurred along the study route, which agreed with the [45] annual report and other published work [46]. This underreported accident might be due to a lack of modern equipment for accident reports, poor reporting standards by officials, and lack of adequate security. More so, accidents that happened late in the night (10:00 pm - 11:59 pm) or early hours (12:00 am - 6:00 am) of the day may not be reported as officials cannot be at all locations simultaneously.

Based on the accident locations, the study area was divided into four sections: section I (Lokoja-Kotonkarifi), section II (Kotonkarifi-Abaji), section III (Abaji-Abuja), and section IV (Abuja-Kaduna). Each section has routes, and each route contains specific locations. In the northbound direction, 47 out of the 90 locations had accidents ten times or more, as shown in **Table 3**. The southbound direction consists of 93 accident locations, out of which 38 locations have accidents ten times or more, as shown in **Table 4**. These locations have more significant accidents between 2013 and 2017, raising the need for further detailed analysis of the locations.

Table 1. Accident severity along Lokoja-Abuja-Kaduna highway.

		Fatalities		Injuries	
Year	No of Accidents	Frequency (F)	%	Frequency (F)	%
2013	1285	1154	40.46	996	25.50
2014	861	818	28.68	767	19.64
2015	815	271	9.50	737	18.87
2016	704	195	6.84	621	15.90
2017	991	414	14.52	785	20.10
Total	4,656	2,852	100	3,906	100

Table 2. Contributory causes of road traffic accidents along Lokoja-Abuja-Kaduna Highway (2013-2017).

		2013		2014		2015		2016		2017		Total	
NO	Contributory Cause	F	%	F	%	F	%	F	%	F	%	F	%
1	Speed Violation	286	21.95	279	26.27	309	30.21	288	29.24	416	29.44	1578	27.27
2	Loss of Control	370	28.40	274	25.80	231	22.58	133	13.50	224	15.85	1232	21.29
3	Sign Light Violation	63	4.83	102	9.60	122	11.93	254	25.79	386	27.32	927	16.02
4	Tyre Burst	142	10.90	137	12.90	133	13.00	97	9.85	125	8.85	634	10.97
5	Wrongful Overtaking	184	14.12	62	5.84	44	4.30	25	2.54	45	3.18	360	6.22
6	Dangerous Driving	103	7.90	60	5.65	67	6.55	54	5.48	45	3.18	329	5.69
7	Route Violation	47	3.61	50	4.71	51	4.99	55	5.58	53	3.75	256	4.42
8	Dangerous Overtaking	27	2.07	19	1.79	08	0.78	07	0.71	23	1.63	84	1.45
9	Mechanically Deficient Vehicle	17	1.35	12	1.13	06	0.59	15	1.52	31	2.19	81	1.40
10	Brake Failure	08	0.61	22	2.07	16	1.56	10	1.02	15	1.06	71	1.23
11	Others	19	1.45	13	1.22	12	1.27	08	0.81	12	0.85	65	1.12
12	Road Obstruction Violation	10	0.76	14	1.32	12	1.17	13	1.32	13	0.92	62	1.07
13	Fatigue	09	0.69	04	0.38	03	0.29	18	1.83	16	1.13	50	0.86
14	Driving under Alcohol/Drug	09	0.69	05	0.47	05	0.49	03	0.30	03	0.21	25	0.43
15	Overloading	02	0.15	02	0.19	0	0	02	0.20	03	0.21	09	0.16
16	Sleeping on Steering	01	0.07	04	0.38	03	0.29	0	0	0	0	08	0.14
17	Bad Road	01	0.07	02	0.19	0	0	02	0.20	01	0.07	06	0.10
18	Use of Phone While Driving	02	0.15	01	0.09	0	0	01	0.10	01	0.07	05	0.09
19	Poor Weather	03	0.23	0	0	0	0	0	0	01	0.07	04	0.07
	Total	1303	100	1062	100	1022	100	985	100	1413	100	5786	100

Table 3. Northbound locations with number of accidents of 10 or more (2013-2017).

No.	Accident Location	Total Number of Accidents	No.	Accident Location	Total Number of Accidents
1	Gadabiyu town	86	25	Doka	16
2	Awawa	53	26	Idu Bridge	15
3	Manderegi	52	27	Giri Inter.	15
4	Banda	48	28	Rijana	15
5	Ahoko Village	40	29	Bako Village	14
6	Kara	39	30	FGC Kwali	14
7	Gwako Village	33	31	Anagada U-turn	14
8	General Hospital Inter. Kw	28	32	Azara Town	14
9	Okpaka	26	33	Kwaita	13
10	GSS Yangoji	26	34	Zuma Rock	13
11	NATACO Junct.	24	35	Gidan Busa	13
12	Small Sheda	24	36	Kwali Mrkt. U-turn	12
13	Gaba Hill	22	37	Opp. Coll. Of Edu. Zuba	12
14	SLAN F/ST	21	38	Madalla Inter..	12
15	OZI Village	20	39	KM14 DM Kurfi	12
16	KM85 Katari	19	40	Bishini Inter.	12
17	Ahoko bridge	17	41	Toll gate SBW	11
18	Aseni Village	17	42	Ohono	10
19	SDP Junct	17	43	Chikara Village	10
20	T/Maje U-turn	17	44	Fire Serv. Coll. Kwali	10
21	Akilibu	17	45	Zuba U-turn	10
22	Adabo Village	16	46	Polewire	10
23	Big Sheda U-turn	16	47	Maro	10
24	KM11 Murada	16			

Table 4. Southbound locations with number of accidents of 10 or more (2013-2017).

No	Accident Location	Total Number of Accidents	No	Accident Location	Total Number of Accidents
1	Chikara Village	110	20	Big Sheda U-turn	17
2	Kwaita	108	21	Giri Inter.	17
3	Piri	94	22	Rijana	17
4	Banda	48	23	Doka	17
5	T/Maje U-turn	44	24	M/M Bridge	17
6	Akilibu	36	25	GSS Yangoji	16
7	Omoko	35	26	Jamata Curve	15
8	Gadabiyu town	34	27	Awawa	14
9	Bako Village	30	28	Zuba U-turn	14
10	Anagada U-turn	28	29	Akpogu Village	13
11	Opp. Marist Coll.	25	30	Small Sheda by NASC	13
12	SLAN F/ST	25	31	Gwako Village	13
13	Aseni Village	22	32	Sabon Gari Gadabiyu	12
14	Gidan Busa	22	33	Okpaka	12
15	Bulletin	21	34	Zuba Inter.	12
16	Naharati	21	35	Dankogi	11
17	KM 85 Karari	21	36	Gen. Hospt. Inter. Kwali	10
18	Kotonkarifi	18	37	NNPC F/ST.	10
19	Opp. Coll. Of Edu. Zuba	18	38	KM 8 SBW	10

Inter. = Intersection

4.2. Spatial Distribution of Accidents

A field survey was carried out to identify the spatial distribution of accidents along the highway. The GPS coordinates of the affected locations were obtained. The GIS tools were used to show the accident locations on a digital map and analyze traffic accidents' hotspots. Weighted mean center, KDE, Moran's I Statistic, Fishnet polygon, and Network spatial weight matrix were used to show the spatial nature of the accident locations.

4.2.1. Mean Center Analysis

Figure 2a illustrates the geographic mean center for the cumulative accident frequency (2013-2017) and the individual years. It can be observed that there was a shift in the concentration of road traffic accidents along the highway from Gadabiu town near the Dangara intersection in 2013 toward Yangoji town in 2014. A backward shift of the geographic mean center of accident frequency is observed for 2015 toward Fukafu town. In 2016, the mean center shifted forward again. This time was found at Sabon Gida town, and 2017 recorded the maximum shift in the mean center of accident locations toward Rafin Pa near the airport intersection of the FCT road. The overall mean center is located somewhere midway between Sabon Gida and Yangoji on a highway curve. This suggests that highway intersections and curves somewhat influence accident occurrence.

4.2.2. Density Analysis

Figure 2b represents the KDE surface for the cumulative accident frequency across the study route. The density surface readily depicts the spatial variation in accident frequency from high to low. However, this is a subjective map, as it reveals nothing about the statistical significance of the high or low accident frequency at locations across the study route. In other words, these variations could be a result of a random process and not necessarily tied to a cause. The density surface concerning the road network indicates that overall high-frequency accident locations are associated with road intersections (e.g.

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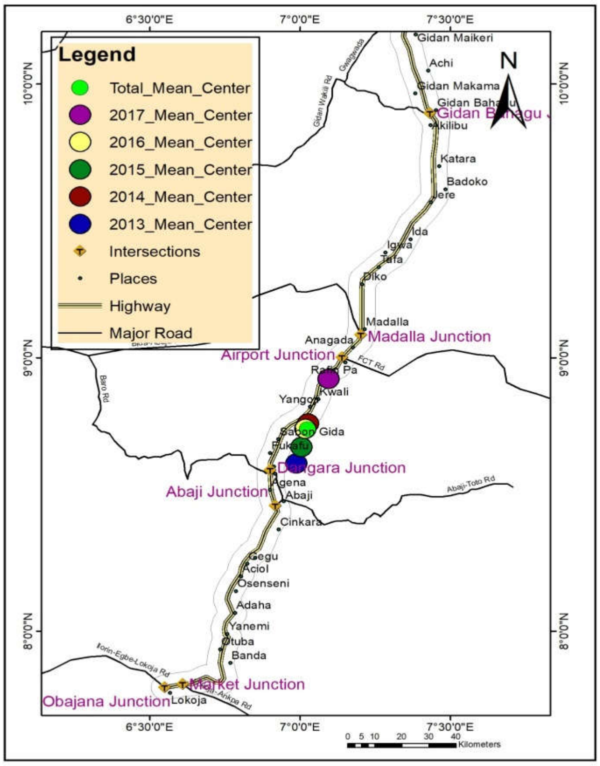
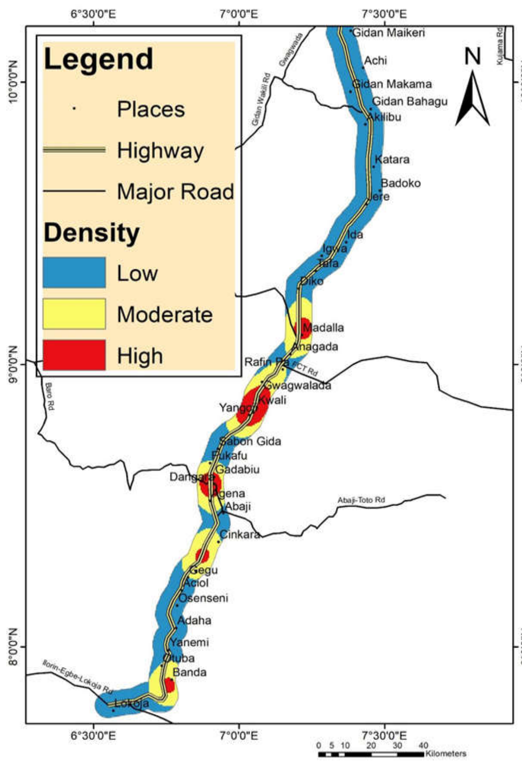
at Madalla and Dangara intersections) and the road curve near Banda town south of the study route.



(a) Shift in geographical mean of accident frequency

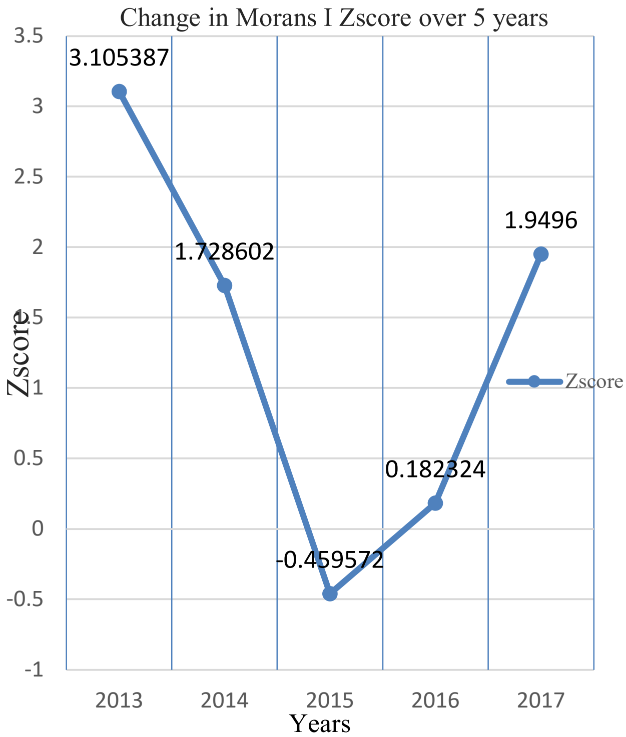


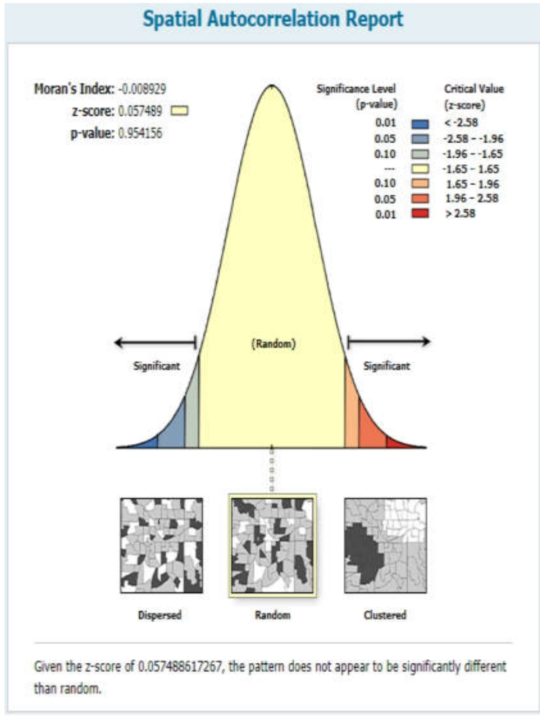
(b) Total hotspot map for 2013-2017

Figure 2. Results of weighted mean and total density.

4.2.3. Cluster Analysis

The result of spatial autocorrelation (Moran's I) statistics of accident data for the 5 years is graphically illustrated in **Figure 3a**. The graph is a plot of the z-scores for each year against the years. From the curve, it can be deduced that only in 2013 was there a significant cluster of high values of accident locations given a z-score of 3.10538 with a less than 1% likelihood that the cluster could result from a random process; hence the null hypothesis is rejected. The z-scores 1.7286 and 1.9496 for 2014 and 2017 respectively indicate a lesser intensity of clustering with a 90% confidence interval and a 10% likelihood that the clusters could result from a random process. The z-scores for 2015 (-0.459572) and 2016 (0.182324) indicate that the pattern of accidents for the 2 years does not appear to be significantly different from random. However, **Figure 3b**, which represents the Moran's I result for the cumulative accidents, shows no overall accident clustering for the 5 years; the pattern is otherwise random.





(a) Change in Moran's I Z-score between 2013 and 2017 (b) Report of Moran's I: The total of accidents for the 5 years.

Figure 3. Line chart of Z-score and the Moran's I total accidents report.

4.2.4. Hotspot Analysis

Figure 4 represents the map output of hotspot analysis using a fishnet polygon. The map demonstrates a statistically significant clustering of the fishnet cells with a higher number of aggregated accident locations around the center of the study route closely associated with the Madalla and Airport intersections. It is noteworthy that the estimated hotspot is localized in a part of the study route where there is a relatively abrupt change in land elevation per unit distance on the highway. This perhaps is a contributing factor to accident frequency in this hotspot marked route.

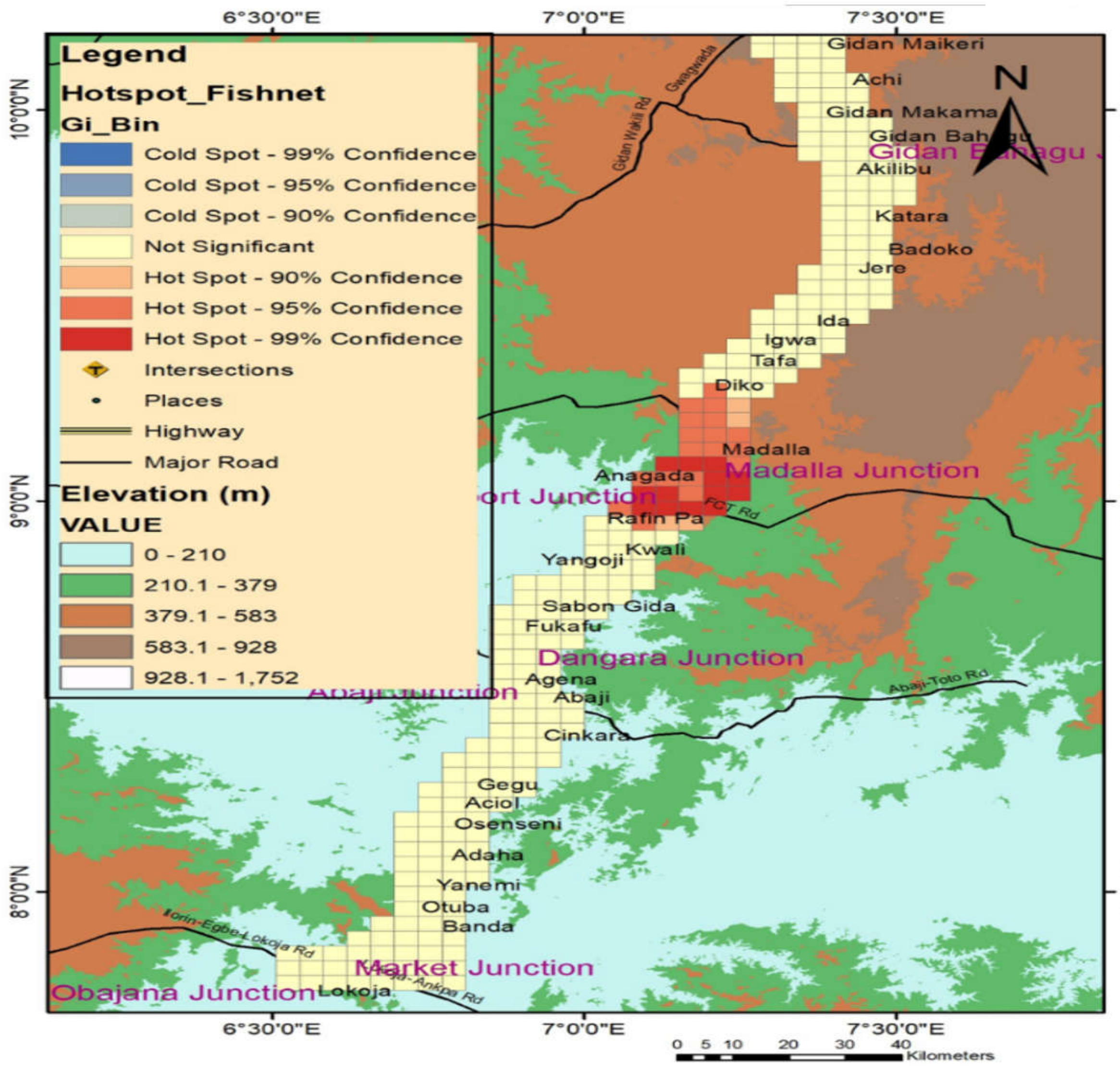


Figure 4. Accidents hotspot map of the study route using a fishnet polygon bounded by the highway buffer polygon.

The outputs of hotspot analysis using a network spatial weight matrix for each year from 2013 to 2017 are represented in **Figure 5 (A—E),** respectively. There appears to be a shift in the hotspot location from the highway south end in 2013 (at the road curve near the market intersection and Banda town), to the center of the study route in 2014 (near Dangara and Abaji intersections), to the north end of the highway in 2017 (near Gidan Bahagu intersection). There are however, no hotspot locations for accidents record for 2015 and 2016. Also, the cumulative accident record for the 5 years expresses no hotspot locations, as shown in **Figure 6.** As shown in **Figure 5(A), (B),** and **(E),** the hotspot locations with high confidence levels are at points with geometric characteristics, such as intersection, curves, bridges, u-turns, interchanges, grades, hilly terrain, roadside obstacles, and median barriers.

In 2013, based on accident frequency at each of the 88 locations, the standard deviation measurements showed 17 locations with a z-score above 2.0 standard deviations. Five of these 17 locations include the top 10 highest motor vehicle accident locations found to have a z-score above 2.0 as determined with the hotspot analysis. In 2014, based on the accident frequency, the standard deviation measurements showed 5 locations with a z-score above 2.0 standard deviations. Two of these 5 locations include values that are significantly higher than the rest 3 within the neighborhood. In 2017, standard deviation measurement found 7 locations with a z-score above 2.0 standard deviations. One of these

7 locations stands out to as a spot with less than 1% likelihood that the clustering of road accidents results from a random process.

Therefore, if the decision were to be taken based on these results, it would be better to look at the statistically significant clusters of high accident frequency for each year. Perhaps the shift in accident hotspots over the years is attributable to pavement failure (a common feature of Nigerian roads) and other factors, such as reckless driving, absence of or inadequate traffic signs, and the vehicle worthiness.

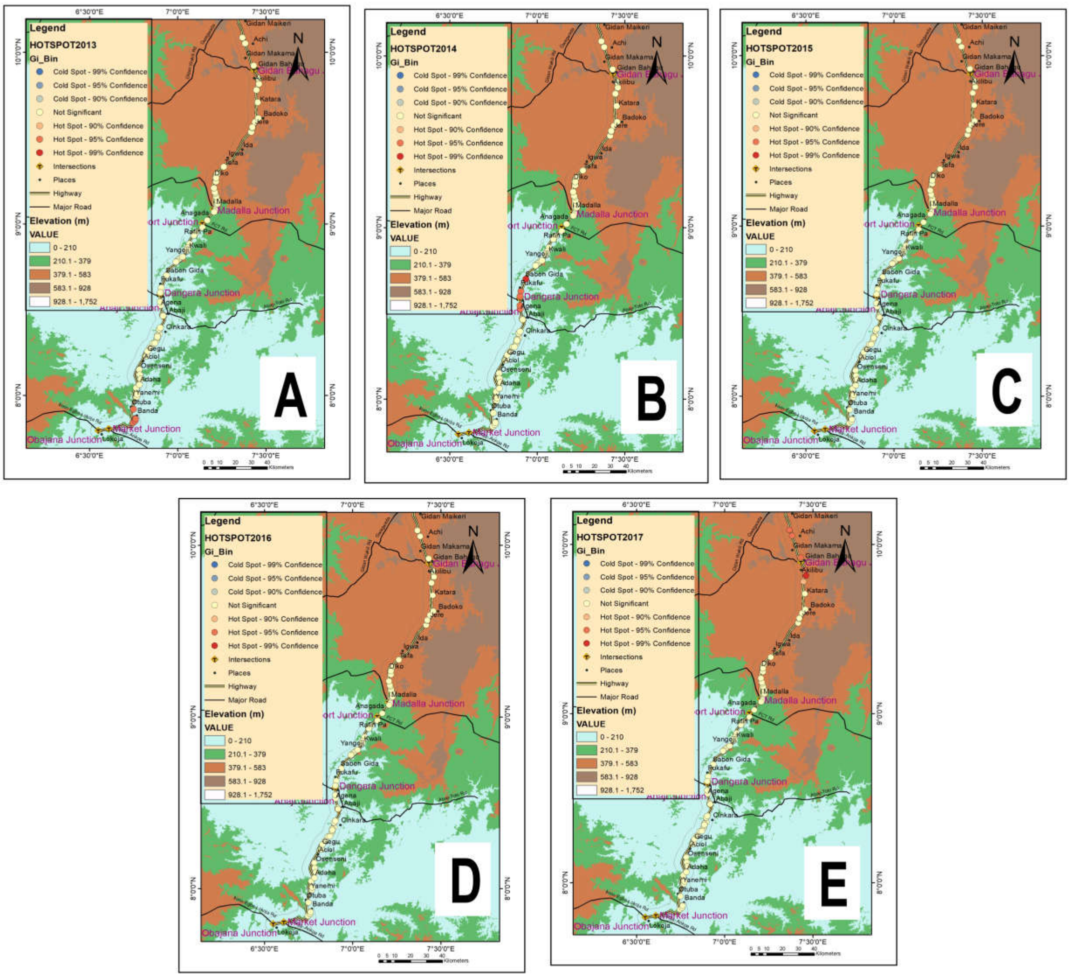


Figure 5. Hotspot analysis: (a) 2013, hotspot exits with 95% significance, (b) 2014, hotspot exits with significance between 95% and 99%, (c) 2015, no hotspot exits, pattern is random, (d) 2016, no hotspot exits, pattern is random, and (e) 2017, hotspot exits with significance between 95% and 99%.

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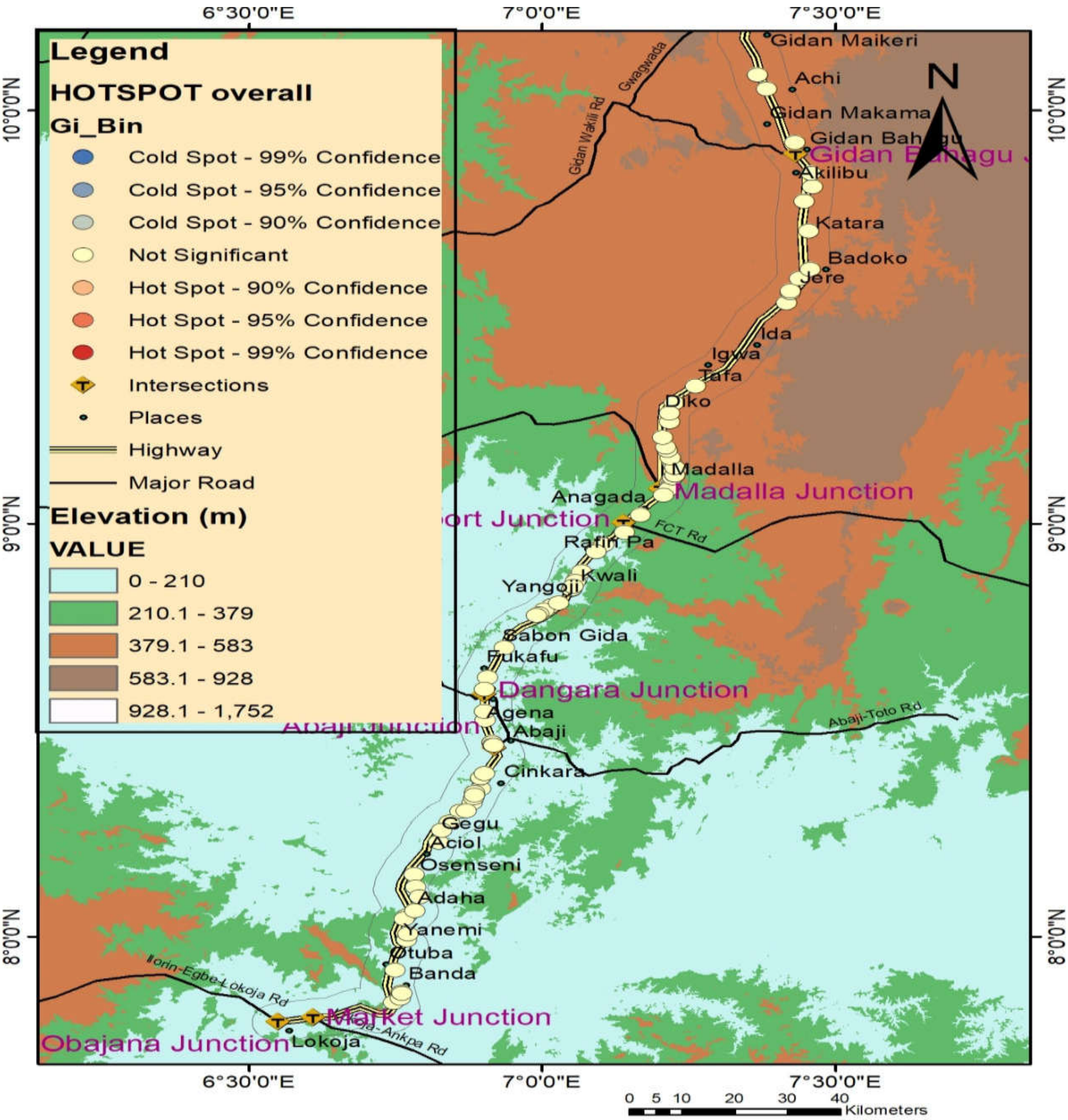

Figure 6. Overall hotspot analysis for the 5 years (2013 and 2017).

4.3. Traffic Exposure

Traffic counts were conducted to determine the effect of traffic volume at the hotspot locations on accident occurrence. **Table 5** shows the traffic data for the sections where hotspots were identified. The locations within Abaji-Abuja have the highest number of ADT of 31,270 for the northbound direction and 16,303 for the southbound direction. Other sections have ADTS that are less than 10,000. As expected, the sections with larger traffic volumes have more accidents than those with lesser traffic volumes.

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Table 5. Traffic data at hotspots.

No.	Section	Direction[a]	Hotspot Locations	ADT
1	Lokoja-Kontokarifi	NB	Banda, Market Intersection, Karara	4903
		SB		3836
2	Kontokarifi-Abaji	NB	Sabon Gida, Agena, Pukafu, Dangara Intersection	5600
		SB		4960
3	Abaji-Abuja	NB	Abaji Bridge, Gen. Hospt. Intersection Abaji, Abaji U-turn	31270
		SB		16303

4.4. Geometric Characteristics of Hotspots

Accident occurrences along the study route are not evenly distributed at the hotspot, as some occurred at locations with geometric features. From **Table 6**, most accidents occurred at horizontal curve locations, u-turns for villages and small cities, bridges, t-intersections, and roadside objects. Other accidents occurred at locations with a settlement, vertical curves, roadside parking, and eroded shoulders **(Figure 7)**. These results agree with [47,48], who inferred that highway geometric features, roadside characteristics, and road design, among other factors, were the significant causes of road accidents in developed and developing countries. According to the FRSC report, high speeds at some hotspots are the primary cause of accidents at the locations. Driving at high speeds at sharp horizontal curves tend to result in accidents as the vehicle may swap away from the road surface. **Figure 8** shows the frequency of accidents at the hotspots identified for 2013, 2014, and 2017.

Table 6. Geometric characteristics of the hotspots identified for different years.

Year[a]	Location Name	Geometric Characteristics[b]	Major Accident Causes[c]	C.L.(%)	Suggested Improvement
2013	Market Inter.	HC, Built-up area, eroded shoulder	High speed	99	Pedestrian bridge/parking lot
	Banda	HC, roadside obstacle (hill)	High speed	99	Speed limit
2014	Fukafu	HC, built-up area,	Sign violation	99	Proper signpost
	Dangara Inter.	Built-up area, U-turn, T-intersection	LOC	95	Proper signpost
	Agena	HC	High Speed on sharp curve	95	Reconstruction
	Abaji Bridge	HC	Wrongful overtaking	95	Speed limit &signpost
	Gen. Hospt. Abaji	T-intersection,	High speed	90	Speed limit & signpost
	Abaji U-turn	U-turn	Fatigue	99	Reconstruction
	NAHARATI Abaji	U-turn, bridge, built-up area, vertical curve	LOC/pavement failure	90	Reconstruction
	Sabon Gida	HC, truck parking on shoulder & deceler. lane, U-turn	LOC	99	Proper road marking and signpost
2017	Achi	Vertical curve	LOC	95	Proper road marking and speed limit
	Gidan Bahagu	U-turn	Fatigue	95	Reconstruction
	Akilibu	Horizontal curve, T-intersection	Road obstruction	99	Intersection signalization
	Karara	Bridge, horizontal curve	High speed	90	Signpost required

[a]No hotspots for 2015 and 2016, [b]HC = horizontal curve, [c]LOC = loss of control, C.L. = confidence level.

(a) Sharp horizontal curve at Agena (b) Vertical curve at Achi area (c) Trucks parking on deceleration lane at Sabon Gida

Figure 7. Hotspot locations along the study sections.

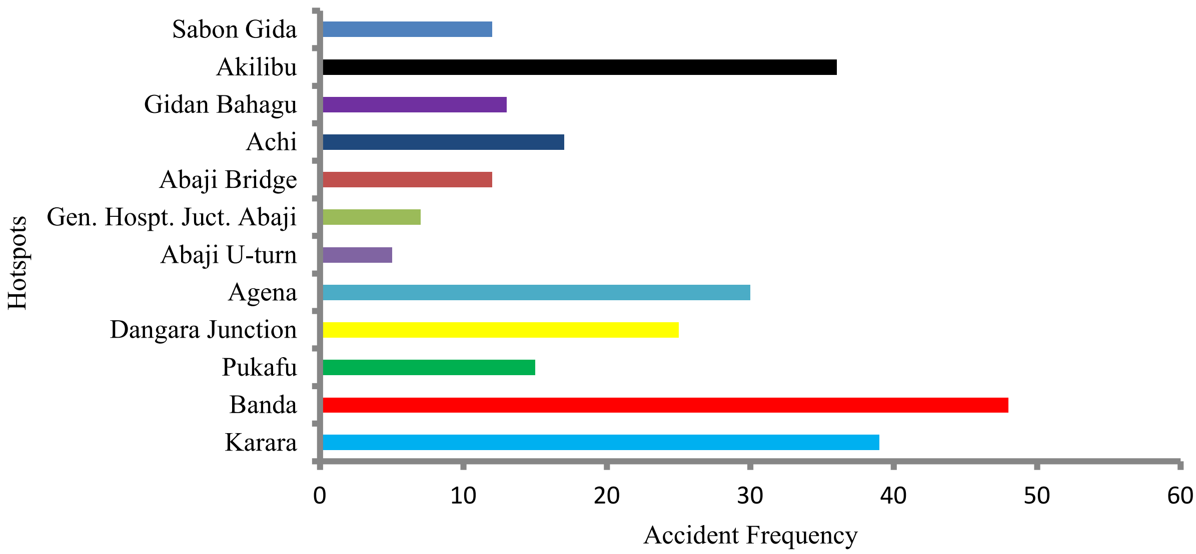

Figure 8. Accident frequency at the hotspots (2013, 2014, and 2017).

5. Discussion

The number of accidents at network locations per year was identified based on the subjective analysis method of accident data. This provides the primary indicator for the possible situation of the particular safety problems at locations. This unrealistic method can lead to false identification of hotspots and prioritizing the sections improvements. This method is not in tandem with the criteria outlined by [7] for hazardous road location identification.

The weighted mean center represented the concentration of road traffic accidents along the highway. This shows the shift in the geographical mean of accident frequency in the study route. The analysis indicated the overall mean center at mid-way between Sabon Gida and Yangoji on curves at the study route as shown in **Figure 2a**. This justifies the findings by [47], which inferred that geometric features, among other factors, are responsible for accident occurrences.

Figure 2b indicates the KDE, which is highly responsible for visual detection. The KDE map shows the total frequency of accident locations related to road intersections such as Madalla and Dangara intersections and road curves at Banda town. However, it only addresses the first-order properties in hotspot spatial analysis of points without considering the spatial dependence and statistical significance of the interaction among the number of events in a given location [30].

The second-order effects of the spatial process were examined using GOG, which evaluates the extent to which a variable at a given location affects those of the neighboring locations [11]. As noted in **Figure 3a,** only in 2013 there was a significant cluster of high accidents with a z-score of 3.1054, P-value of 0.0019 and Moran's I index of 0.1263. Z-scores of 1.7286 and 1.9496; p-values of 0.0839 and 0.0512; and Moran's I index of 0.0638, and 0.0799 for 2014 and 2017, respectively, indicate a lesser clustering intensity. Also, z-score = -0.4596 and 0.1823; p-values = 0.6458 and 0.8553, and Moran's I index = -0.0320 and -0.0032 for 2015 and 2016, respectively shows that the accident pattern for the 2 years is random. the cumulative accidents with z-score = 0.0575, p-value = 0.9542 and Moran's I index of -0.0089 indicate that there is no overall clustering and that the accident occurrence for the 5 years does not appear to be significantly different from random.

The hotspot analysis involved two approaches of GOG statistics. The fishnet polygon and the network spatial weight matrix. The fishnet cells were statistically significant with many accident locations around the Madalla and airport intersection in the study route. Land elevation per unit distance contributes to accident occurrences in the study route, as the estimated hotspot is localized in some areas. The network spatial weight matrix shown in **Figure 5** indicates hotspot analysis for 2013 to 2017. There are shifts in the hotspot location from one year to the other. The hotspots exist for 2013, 2014, and 2017 with a 95-99% significance level. This occurs at locations with geometric features such as curves and intersections. The hotspots do not exist for 2015 and 2016 since the patterns are random. Also, the cumulative accident record for the 5 years shows no hotspots exist **(Figure 6)**. Over the years, the shift in accident hotspots can be attributed to other accident causative factors (human, vehicle, and environmental).

The influence of traffic exposure on the hotspot locations is very significant at the Abaji-Abuja sections, which comprise the following hotspot locations: Abaji bridge, General hospital intersection Abaji, and Abaji u-turn. An ADT of 31,270 was obtained for the NB direction and 16,303 for the SB direction. This high traffic exposure contributes to accident occurrence at the hotspots as the section is a built-up area with commercial centers located along the route. Other sections in the study route have relatively low traffic volume, which is not significant and does not influence the hotspots. In addition, the underreported accident is envisaged to influence the accident hotspot determination. The lack of adequate data capturing equipment, inexperience by officials, and unavailability of officials at all locations for 24-hours a day and 7 days a week might have resulted in some accidents not being captured.

6. Conclusion

This study identified high-risk locations (hotspots) representing the first step in a safety improvement program. Accident locations from the primary and secondary data sources were mapped. The accident concentrations at the locations were determined using the weighted mean center and KDE methods. These locations were further verified using two different approaches of the GOG statistic (fishnet and network spatial weight matrix). Based on this study, the following conclusions are made:

1. The concentration of road traffic accidents is at mid-way between Sabon-Gida and Yangoji curves as indicated by the weighted mean center analysis.

2. Based on the visual detection carried out using KDE, the frequency of accident locations is associated with road intersections (such as Madalla and Dangara intersections) and road curves at Banda town.

3. Hotspots exist with a significance level between 95-99% for 2013, 2014, and 2017. The cumulative hotspot map indicates that no hotspots exist for 2014 and 2015 as the pattern is random. Thus, preventive measures for the hotspot locations should be based on a yearly hotspot analysis.

4. The spatial autocorrelation analysis of the overall accident locations with a z-score = 0.0575, P-value = 0.9542, and Moran's I statistic = -0.0089 showed that the distribution of accidents on the study route is random.

5. Traffic exposure is significant on accident hotspot at Abaji Bridge, Gen. hospt. Abaji, and Abaji U-turn. Thus, precautionary measures should be put in place at these locations.

6. Future work is required to check the consistency of highway geometric features, reliability analysis of geometric design features, reliability analysis of geometric characteristics, and the relationship between the reliability and objective safety measures. Variability in the quality of construction work by the contractors also needs to be checked. The future work will help identify geometric features that need to be redesign or reconstructed.

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Abbreviations

The following abbreviations were used in this paper:

ADT = average daily traffic

DI = dangerousness index

EB = empirical Bayes

FMWT = Federal Ministry of Works and Transport

FRSC = Federal Road Safety Commission

GIS = geographic information systems

GOG = Getis-Ord Gi*

GPS = global positioning system

HC = hierarchical clustering

KDE = Kernel density estimation

KDE+ = extended KDE

NB = northbound

SB = southbound

STAA = spatial traffic accident analysis

SANET = Spatial Analysis along Network

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