ANALYSIS OF OIL SPILL RISK USING SPACE-TIME PATTERN OF INCIDENTS IN THE NIGER DELTA, NIGERIA

LAWAL OLANREWAJU*, IKPO, ROLAND CHIMENWO**
*Department of Geography & Environmental Mgmt., Faculty of Social Sciences, University of Port Harcourt, Nigeria
**National Oil Spill Detection and Response Agency, Port Harcourt Zonal Office, Rivers State, Nigeria
olalaw@hotmail.com

Abstract: **Oil spills are hazardous due to their impact on the people, the environment and economic wellbeing of the society. The study examined the space-time trend and pattern of oil spills in the Niger Delta (2006-2016). Data were sourced from the National Oil Spill Detection and Response Agency (NOSDRA). Mann-Kendal trend and Getis-Ord Gi* statistics were used to identify the spatial and temporal trend. A total of 6,487 incidents were identified, about 31% were recorded on Tuesday and Wednesday while the highest number (10%) of incidents occurred in May. The average nearest distance among events indicates spatial clustering, as the observed mean distance (0.29km) is significantly (Z-score -121.69, P < 0.01) smaller than expected mean distance (1.39km). Of the 8,900 total locations (grid size of 2.8km, 132 months), 941 (10.57%) contain at least one incident for at least one-time step interval. These 941 locations comprise 124,212 space-time bins of which 4,262 (3.43%) have incident counts greater than zero. These resulted in trend statistics of 10.61 (P<0.05), indicating that there is a statistically significant increase in point counts over time (monthly). Statistically significant event grids (62) were found to be hot spots. These hot spot clusters are spread across Bayelsa (4), Delta (2) and Rivers (3) States. The results gave a clear indication of the areas where over time and space oil spills are prominent. Thereby, identifying statistically significant space-time pattern of incidents which could inform mitigation measures and facilitate the implementation of adequate risk management and contingency planning**.

Keywords: Oil exploration; Oil theft; Emerging Pattern; Spatio-temporal Risk Analysis

1 INTRODUCTION

Apparent across any landscape are hazards, however, inaction, inadequate and inappropriate actions often turn such into a disaster. Oil spills are hazardous due to their impact on the people, the environment and economic wellbeing of the society. They have a significant impact on the achievement of the 12th, 13th and 14th SDG in Nigeria. Thus, a clear understanding of their trend in space and over time is essential to ensure that adequate measures are prescribed to address them. To this end, the collection and proper analysis of available data on oil spills across the country can provide a better understanding of spills as well as support the development of measures that can help in limiting the occurrence and extent. This study examined the space-time trend and pattern of oil spills in the Niger Delta (2006-2016). The aim is to identify emerging space-time pattern, thus, providing a framework to support risk reduction and emergency management.

An oil spill could be as a result of an accidental release of oil from platforms, tankers, wells, rigs, etc. into either the marine or terrestrial environments[1]. The causes of this release vary and include operational error, equipment failure, corrosion, accident as well as sabotage. Over the years there have been numerous examples of major oil spills in Nigeria, a look at the Oil Spill Monitor (https://oilspillmonitor.ng/) gives a clear indication that the occurrence of such disaster is a major scourge on the environment (Figure 1) of the oil-producing regions of the country.

It is very clear that even with the best laid out plan, the management of disasters requires an iterative and continuous evolution of techniques, actions, and measures. Oil spills' impacts are often worse due to lack of adequate data and information to guide actions and deployment of resources for preparedness and response.

Oil and gas exploration is very vital for the Nigerian economy contributing to about 8.55% of the GDP [2]. However, the lack of commensurate development across many of the oil-producing communities has created a situation of incessant agitation and conflict between these communities, the government, and the multinationals.Oil and gas exploration in the Niger Delta has resulted in significant environmental impacts which could also be linked to social problems [3-5].

In Nigeria, there have been efforts to curtail oil spill incidence, some of these led to the National Oil Spill Detection and Response Agency Act 25 of 2006. This established the National Oil Detection and Response Agency (NOSDRA) which is tasked with the coordination and the execution of the National Oil Spill Contingency Plan (NOSCP). The Oil Spill Monitor (Figure 1) is one of the tools used by the agency for reporting of spills in the country as part of their responsibility. Despite all the effort across several agencies, the problem oil spill is still very common in the Niger Delta Region. This could be partly attributed to the trend in oil theft and artisanal refining [6]. Some of the product refined are sold to the local markets and others on larger-scale operations sells to the international markets [6, 7]. The inefficiency of the operation results in the dumping of about 80% of the heavy end crude not being refined [6] into the creeks and streams around such facilities. Some of which gets trapped within the mangroves while others end up in the coastal waters of the regions.

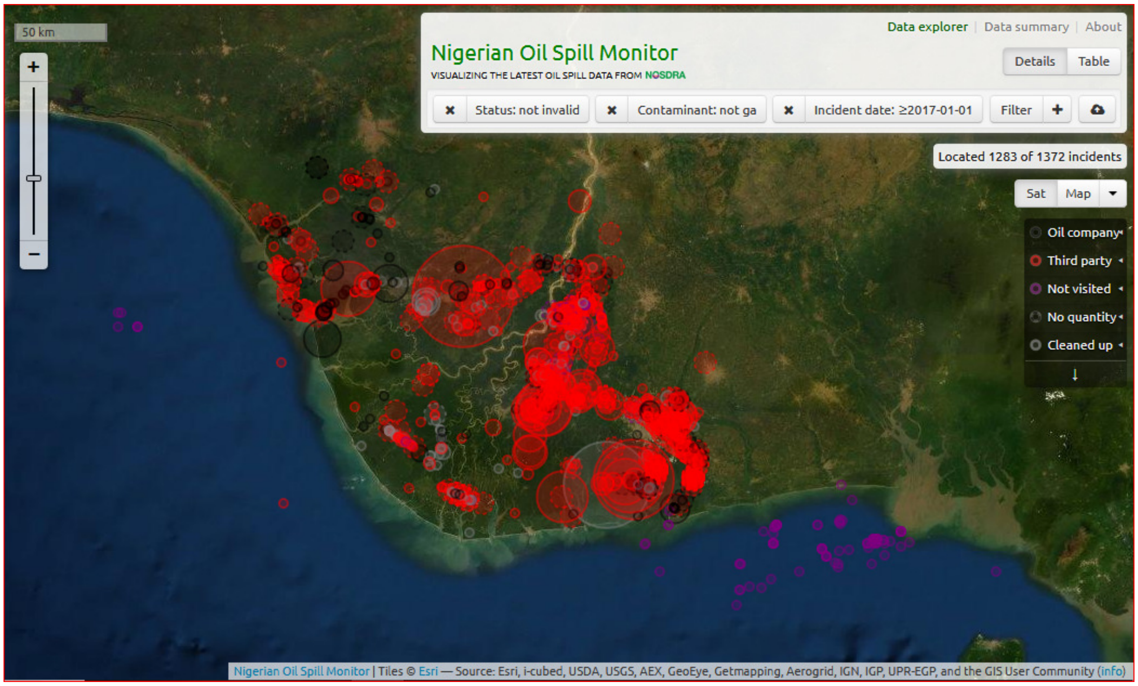


Fig.1 - Snapshot of Incidents of oil spills from 2017 till date

Looking at the spills data available from the Oil Spill Monitor database (2006 to date), sabotage (third party intervention) and equipment failure are the dominant causes of oil spills. With 67% of the spills caused by sabotage, it is evident how the burgeoning illicit industry is literarily fuelling contamination and environmental degradation across the oil-producing regions. It is therefore important to examine the spatial and temporal dimensions of the spills to ensure that efforts at curtailing them are guided by evidence.

Location has a direct impact on every aspect of human activities, and this is evident in economic, sociocultural, and political activities, etc [8] leading to increasing agglomeration of businesses/industries, events, and activities at specific locations. There is a significant body of work on the importance of location for economic activities and development (e.g. Allen, Bourke [9]; Sachs [10]). While these authors identified the importance of location, we cannot ignore the relevance of social and political factors in shaping the pattern of long-term social and economic development.

Temporal analysis of crime or conflict is commonplace, which takes into cognisance the relevance of time in allowing for the interactions among people and between people and things in the creation of a socio-economic system. It is noteworthy, that a perceptively near place may not be visited if the time to travel to it is not allocated. The human-activity decision is not only dependent on space or time, but it is also affected by both spatial and temporal factors – Space-time constraints [11]. From the perspective of oil spills (or crime), constraints such as the level of security, spatial accessibility (by regulators and saboteurs), ease of movement of proceeds, etc. could limit or enable agents and factors.

Space-time analysis can shed more light on the relationship between space and time in relation to the occurrence of certain events. Many of the techniques for this analysis were developed in the field of epidemiology (e.g. Besag and Newell [12]; Knox and Bartlett [13]; Kulldorff and Nagarwalla [14]; Mantel and Bailar [15]). These techniques are also useful in the analysis of crime, conflicts and other events with spatial and temporal dimensions [8].

Glatman-Freedman, Kaufman [16] showcased the application of space-time cluster analysis in the surveillance and detection of enteric diseases in Israel. With the case study of one Health Maintenance Organisation (HMO), they showed that scaling of space-time analysis has the potential for supporting an effective disease control. Iftimi, Montes [17] in their analysis of the relative risk of Varicella disease (an airborne disease affecting children >10 years old), showed that there is space-time clustering of the disease in areas that are economically disadvantaged and with lower participation in vaccination programmes. Thus, identifying where and when efforts need to be concentrated.

Ceccato and Uittenbogaard [18] examined the space-time variation of crime at underground train stations in Stockholm. Their study revealed that crimes are more prevalent around specific time while there is also seasonality coupled with different spatial attributes for different types of crime. The implication, therefore, is that stations' environment influences crime rate over time, thus offering the opportunity for intervention over space and time.

Evaluating the criminal justice system (especially the Stop-Question-Frisk (SQF)) in New York City, Wooditch and Weisburd [19], implemented a bivariate Space-Time Analysis technique (Spatio-temporal Ripley's K Function). This work compared the locations of SQF in relation to daily criminal events. The result showed that the practice produced a modest reduction in crime which extends temporally up to three days and spatially up to 300 feet (after which there is a distance decay). Essentially, their space-time analysis was able to reveal space-time clusters and identify the limit of the cluster over time and space. In the same vein, the space-time pattern of piracy around the Horn of Africa was examined by Townsley and Oliveira [20] using the Knox technique. They reported that there are space-time clusters of pirate activities in this region, thereby providing a framework for supporting the identification of high-risk areas and the formulation of prevention and suppression efforts.

From the foregoing, the study of the pattern is very important in discerning some aspects of the decision making of the actors (in conflicts) or offenders (in terms of criminal activities). Using the optimal foraging concept, offenders might look at vulnerable places and times which can maximise the return on their effort and minimise the risk of being caught (hidden, remote or favourable places where that have loyal agents or co-conspirators). Furthermore, actors in crime could also seek to maximise their gains or minimise their losses. This thus puts the rational choice theory in contention in this situation where the less risky and the simplest ways to achieve the objective is always sought by would-be actors or offenders. Furthermore, one could view the occurrence of oil spills from the perspective of routine activity theory whereby, for an illicit activity to occur three components are necessary. These are a motivated and capable wrongdoer (the criminal); a target (helpless and accessible individual or asset); and non-attendant or skilled gatekeeper to prevent the actions of the wrongdoer [21]. Considering time, targets could be differently vulnerable while gatekeepers could also be differently available, thus time constraints as explained by Hägerstraand [11] modify the behaviour of the actors.

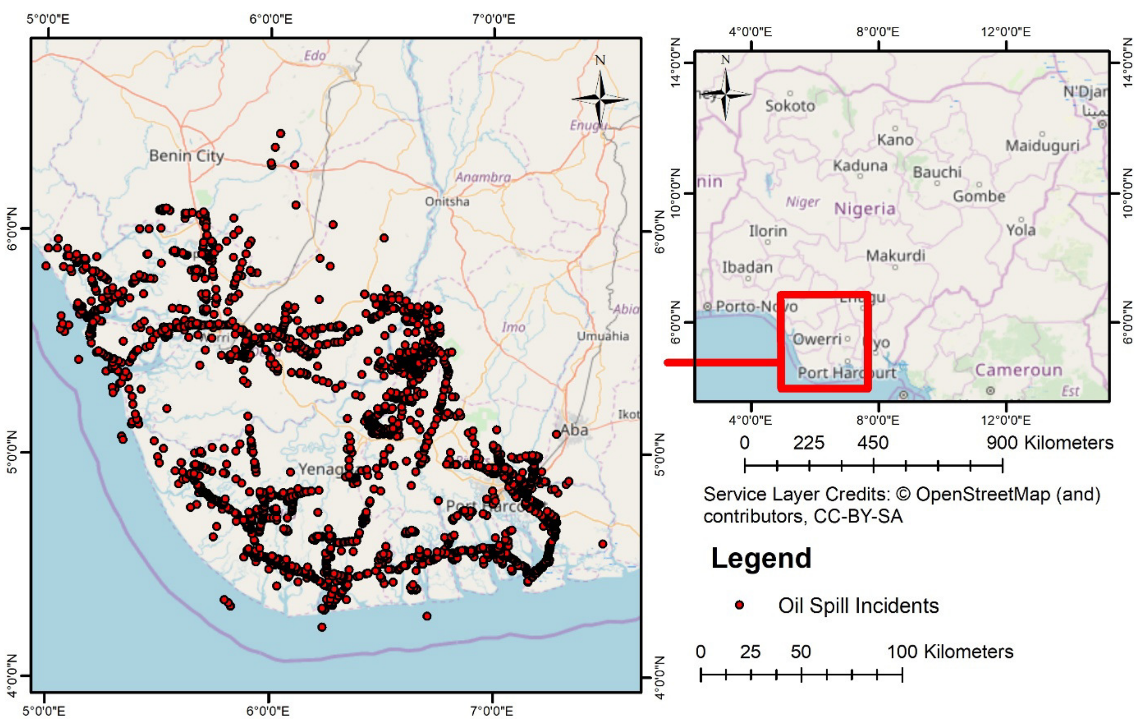


Fig.2 - Distribution of oil spills across the study area (2006 -2016)

2 DATA AND METHODS

2.1 Data

The study utilised data from the Oil Spill Monitor (https://oilspillmonitor.ng/). The dataset consists of location and dates of all reported oil spills (confirmed and yet to be confirmed) from 2006 to date, with details on causes, amount spill, facilities affected, etc. For this study, the data utilised was restricted to confirmed incidents from 2006 to 2016, falling within Bayelsa, Delta, and Rivers States (Figure 2). These States combined have the largest oil and gas wealth of the country and consequently the largest presence of oil and gas infrastructures. The data was subsequently cleaned to remove repeated entries.

2.2 Methods

Descriptive analysis was carried out to examine the frequency of incidents across different periods (year, months and days of the week). The analysis was carried out within the Statistical Package for Social Science – SPSS [22]. Point pattern analysis was carried out using the point interaction approach of Nearest Neighbour Analysis (NNA). This is carried out to examine the spatial properties of the entire body of points (events) across the period of interest. Analyses were carried out for the combined incidents within.

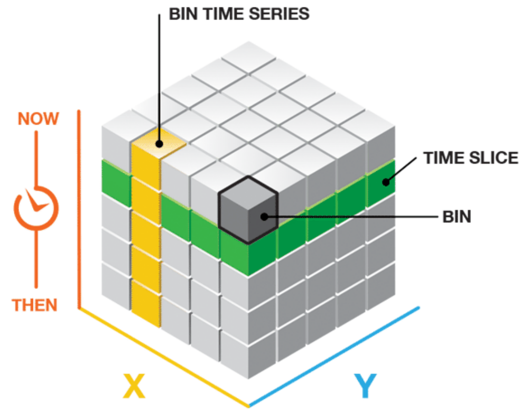


Fig.3 - Space-time data representation within GIS [23]

Space-time analysis of incidents was carried out within a Geographic Information System (GIS) – ArcGIS [24]. This was done to identify the Spatio-temporal clusters of oil spills across the period and the study area. Trends were discerned across the study area over time using the Mann-Kendal Test [25, 26]. This approach is a rank correlation analysis for the bin count (total event) and their respective time sequence. Each period is compared to the one before it and an increase resultsin a value of +1 (an increase over time) while a decrease results in -1 (a decrease over time) and a tie result in zero (no trend over time). This was computed for each time slice (month) and the sum was of this was computed for each of the spatial units (Figure 3). This sums were compared to the expected sum of zero (no trend over time) and using the variance of the values, as well as number of ties and the number of time slices, as the observed is compared to the expected to deduce the z score and a p-value. The trend was examined at monthly (132) intervals.

Emerging hot and cold spots for spills were identified using an adapted version of the Getis-Ord Gi* Statistic [27], the test was adapted for Space-time analyses. This adaptation is a combination of two tests - Mann Kendal Test and Getis-Ord Gi*. With this, it is possible to deduce the intensity of clustering, and values for each bin were considered within the context of its neighbours (bins) for a time slice [28]. The process was carried out in three stages as described by Lawal [8]:

The distance interval for the construction of the grids used for the analysis was computed as follows:

a. compare the density of the oil spill incidents (at all unique points) to the density of random features based on the minimum bounding area covered by the incidents,
b. compute the average nearest neighbour distance for the random features (for the minimum bounding area) and multiplied by 2 (R_{2nn}),
c. if the result is less than the maximum extent of the study area when divided by 100 (E_{m100}) then the distribution is considered dense, then the E_{m100} value is used as the grid size;
d. else if the incidents are not considered dense, then the largest of twice the median or the mean nearest neighbour distance will be used i.e. multiply the mean or the median nearest neighbour by two and choose whichever is the largest value is used as the grid size.

The search radius (*SR*) was calculated using the equation:

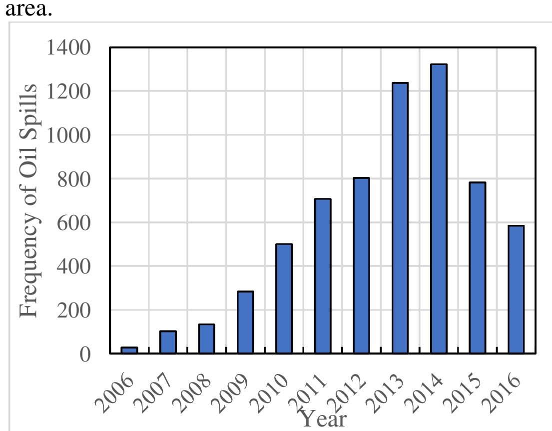
$$SR = 0.9 \times minimum\left(SD, \sqrt{\frac{1}{\ln(2)}} \times D_m\right) \times n^{-0.2} \quad (1)$$

Where *SD* is the standard distance; D_m is the median distance from the mean centre of all event points, and *n* is the number of event points.

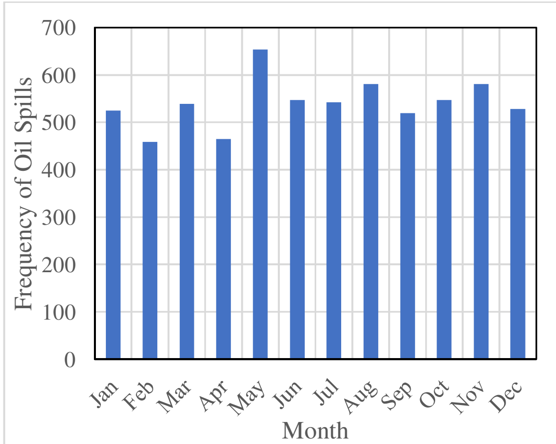
3 RESULTS

3.1 Distribution and Point Pattern Analysis Results

The frequency analysis revealed that across the years about 20% of the oil spills occurred in 2014, this was the peak (Figure 4) of an increasing occurrence which started in 2006. From 2015 there was a decline which was sustained to 2016 with these two years accounting for about 21% of total incidents in the area under consideration. For the months, most of the incidents took places in the month of May (10%) while the lowest total occurrence was recorded for February (Figure 4). Apart from February and April, other months have more than 500 incidents of oil spills (2006 – 2016, across the study area). Examination of the frequency of incidents across the days of the week shows that the proportion ranges between 13% (Sunday) and 15.7% (Wednesday). Sunday, Saturday and Thursday have a total ranging between 841 and 878 incidents while Friday and Monday have 945 and 948 incidents respectively. Tuesday and Wednesday have over 1000 incidents across this period and study area.



(a)

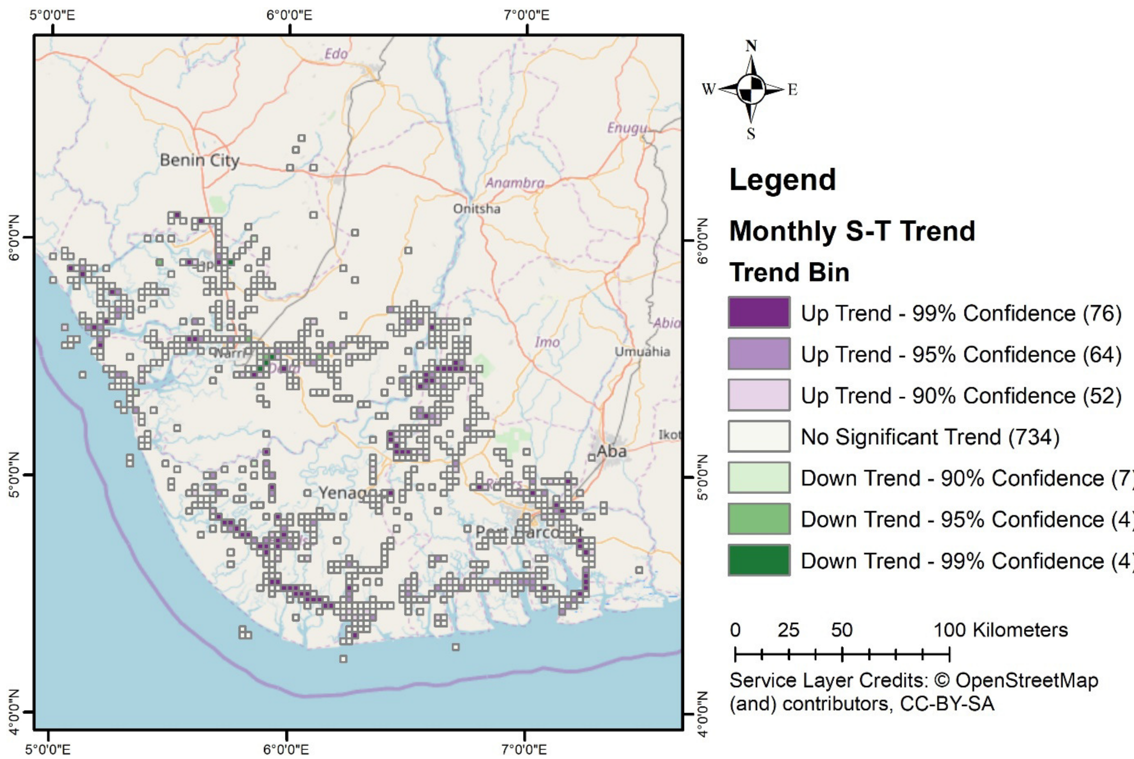


(b)

Fig.4 - Total annual oils spills (2006 - 2016) across the years (a) and months (b)

Two Chi-Square tests of goodness-of-fit were conducted to determine whether oil spills equally occurred across the days of the week and the months of the year. The result showed that oil spills are not equally occurring across the days of the week, X^2 (6, 6487) = 32.35, $p < 0.001$. In the case of the months, oil spills were also not equally distributed across the months, X^2 (11, 6487) = 54,48, $p < 0.001$.

NNA revealed that the average distance from to the nearest neighbour for the incidents is 291.51 m, compared to an expected mean distance of 1386.55 m. Thus, indicating a clustered pattern. With a Z-score value of -121.68 compared to the critical Z-score <-2.58 at a p-value of 0.01, it is apparently that there is less than 1% likelihood that the clustered observed is due to random chance.



pattern

Fig.5 - Space-time trend for oil spills (2006 -2016)

3.2 Space-time Trend

The space-time cube aggregated the 6,487 incidents into 8,900 locations (grid) and each location is 2,764 m. Out of these locations, 941 (10.57%) have at least one incident points all of which amounts to 124,212 space-time bins out of which 4,262 (3.43%) have points counts greater than zero. Overall the direction indicates an increasing trend with Mann-Kendall statistics of 10.61 ($P<0.01$) signifying the presence of a monotonic trend in the series of oil spill incidents. The visualisation of the space-time trend results (Figure 5), shows that locations where different trends within the overall trend can be found.

The results in Figure 5 and 6 shows that about 20.4% of the locations (total of 941) can be discerned as high confidence uptrend while 1.6% have a marked downtrend (Figure 5). Locations with decreasing trend are mostly found in Delta State. While there are individual locations spread across the State i.e. those with a decreasing trend, there is a cluster around the Okpari Creek (near Ughelli). Bayelsa and Rivers States have only one location on the western border with Delta State (Ekeremor Local Government Area - LGA) and the northern border with Delta State (Ogba/Egbema/Ndoni LGA) respectively.

A closer look at Figure 6, showed that there are long tracts in Bayelsa (Southwestern region) and Rivers (Southeastern Region) States with an uptrend in oil spill incidents over time. More so, in the northern parts of these States, there exist several clusters of areas with an uptrend. For Delta State, the locations with uptrend are more dispersed than in Bayelsa and Rivers States. Also, for Delta State, some uptrend clusters were located around Warri, Sapele and the western seaboard (especially around Escravos).

Most of the locations have no discernible trend in time. The lack of trend presents a bigger challenge for designing and implementation of control or mitigation measures as incidents are temporally random. However, further analyses could clearly reveal the interaction of incidents over time and space thus, identify patterns which are not currently captured by the trend as presented in Figure 5 and 6.

3.3 Space-Time Pattern

Two distinct space-time patterns emerged from the analysis (Figure 7) both of which are hot spots – sporadic and consecutive. The remaining locations (majority) across the study area are not statistically significant hot or cold spots. There are 61 sporadic hot spots. These are locations where for less than 90% of the time under consideration (132 months) the locations have been statistically significant hot spots and have never at any point in time been a cold spot. They exhibit an on- and off- characteristics in terms of occurrence of oil spills.

The consecutive hot spots are locations that have never been a hot spot (statistically significant) previously, however, became such in the last time step (final months of 2016) with an uninterrupted run of hot spots bin. Evidently, these places have spills but were never hot spots for oil spills, only recently experienced an intensification of oil spills. One of such locations exits across the study area. This could be found around the cluster of Sporadic hot spots in Ogba/Egbema/Ndoni LGA in the northern part of Rivers State close to the border between this LGA and Ahoada East LGA. These hot-spot clusters identified spread across four, two and three locations in Bayelsa, Delta and Rivers States respectively

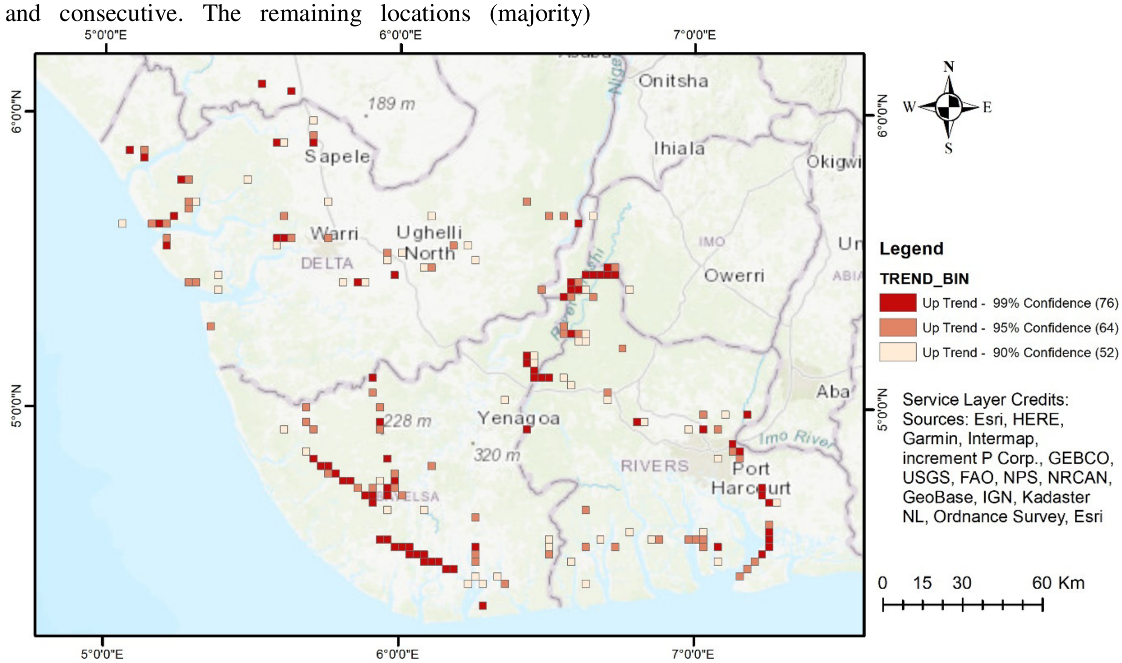


Fig.6: Space-time trend for oil spills – Uptrend locations

.

Examination of the location of the oil spill hot spot and oil infrastructure in the region (Figure 8) identified infrastructures that are mostly at risk across this region. Clearly, the presence of these infrastructures brings about spills. In the northern parts of Bayelsa and Rivers States, hot spots were formed around pipelines and oil fields. Hot spots in the southern parts of Bayelsa is predominantly around a few pipelines with some also around the oil fields. The same was observed in Delta State. With hot spots only formed around these places, it becomes apparent that there are some peculiarities of these places that foster the persistence of oil spills.

A closer examination of the clusters revealed some interesting details about the facilities and the cause of the incidents. Along the longest hot spots cluster found in the southern part of Bayelsa, the 18inch Tebidaba/Brass Pipeline witness a lot of spills and the cause was often due to sabotage/third-party intervention. There are some occasions which were caused by corrosion, equipment failure while some are yet to be determined. This facility is operated by Nigerian Agip Oil Company (NAOC). The second hot spot north-west of this pipeline have spills which are mostly attributed to sabotage, with some cases of equipment failure and corrosion. This hot spot is in the vicinity of 10-inch Clough Creek/Tebidaba pipeline and spills occurred at various part of the oil infrastructure including wellheads, manifolds, wells, delivery line, dehydration unit at tank farm (Brass Terminal). Most of these facilities are also under the management of NAOC. The third hot spot cluster in Bayelsa also in the vicinity of the 10-inch Clough creek/Tebidaba Pipeline. Facilities such as the 4-inch Clough Creek Flowline experienced spills around Azegbene, Gbaraun, Egbemagalabiri. Causes of the spills are equipment failure, corrosion (seldom), sabotage (most common cause) while some cases are yet to be determined.

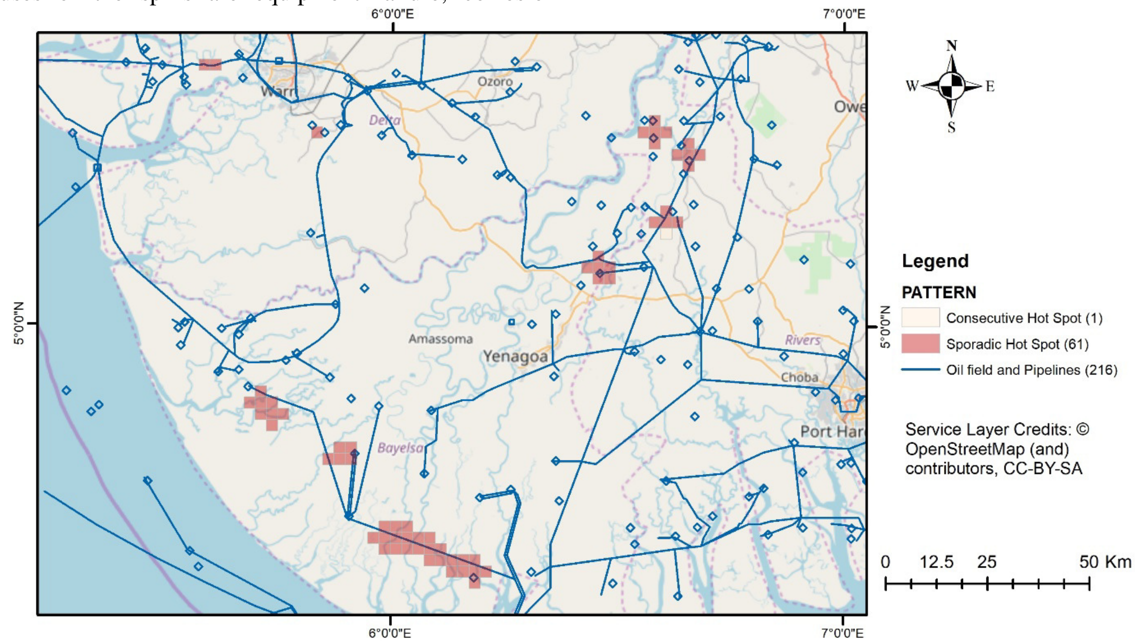


Figure 7: Space-time pattern of oil spill incidents

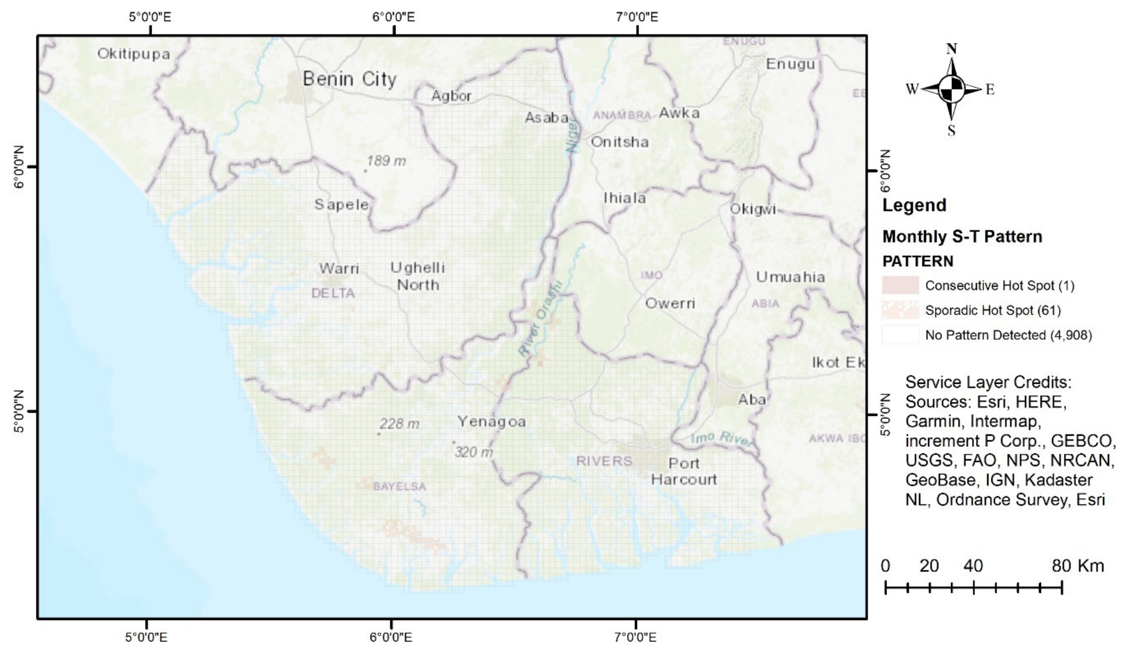


Figure 8: Intersection between Oil field, pipeline and oils spill hot spots

Northwards spanning across Bayelsa and Rivers, the hot spot cluster (Figure 8) occurred around the Trans-Niger Pipeline (14-inch Okordia-Rumuekpe). For this infrastructure, pipeline, trunk line, riser, mini riser, wellheads, flowlines are common sources of the spills. The 12-inch Adibawa-Okordia pipeline could also be found around this hot spot cluster.

Source of spills include pipeline, manifold, delivery line and an oil well at Ubie. Spills were recorded around settlements of Akinima, Oshie, Taylor Creek, Akumoni, Kalaba, Oruama, Anyamabele, Ikarama, Idu-Ekpeye, Akalami and Akara. The facilities around the cluster are under the management of Shell Petroleum Development Company of Nigeria Limited(SPDC) and NAOC. Causes of spills identified include operation and maintenance error, equipment failure, corrosion while sabotage was reported as the most common cause followed by corrosion and equipment failure. Further north of River State, another cluster of hot spots could be found. This was formed around 10-inch Idu Flowline and 14-inch Samabri/Idu Pipeline. The spill sources include wellheads, manifolds, flow Station, flow line, valve leakage and choke box around settlements of Biseni, Idu, Tuburu, and Obinwdu. Facilities around this cluster are operated but TOTAL and NAOC. Around Omoku in River State is another hot spot cluster. This is in the vicinity of the 8-inch pipeline at Idama, 10-inch OB/OB pipeline, 24-inch Ogoda/Brass pipeline, 24-inch Natural Gas Liquids (NLG) delivery pipeline and the 18-inch EOC-Ogoda Pipeline. These infrastructures are managed by NAOC. Spills source includes pipelines, flowlines, flowback lines, manifold, wellhead, isolation gate value, backflush line, flow station, etc. These spills are common around settlements of Ewoama, Obama, Ebegoro Obrikom, Obie-Obor, Obiafu, Okwawiriwa, Mgbede, Ebocha, Omoku, Ogbogene. The most common cause is sabotage and both oil and gas infrastructures were affected. The furthermost cluster occurred along the Omoku axis. Most of the facilities identified as the source of the spills were under the management of NAOC. Both oil and gas infrastructures were affected by the spills. Sabotage was the most common cause of the spill, but equipment failure and corrosion were also identified in some cases. Several equipment failures and corrosion cases were recorded at Obiafu facilities, while the spills are mostly around the settlement of Obiafu, Ogbogene, Ebocha, Obrikom, Umuoru. Flow lines, mini manifold, wellhead, backflush line were the most common sources of the spill.

In Delta State, the first hot spot cluster around the Ubogo axis has all the facilities under the management of the Nigerian Petroleum Development Company (NPDC). Sabotage was recorded as the most common cause of the spills around this cluster. But there were some instances of equipment failure and operation and maintenance error. Flowlines were the common sources of the spills around settlements of Ogbe-Udu, Emadaoja, Ukpiovwin, Ubogo, Okolor, and Uburhe. The second cluster of hot spots in the State could be found around Oteghele. The facilities around this cluster are managed by Petroleum Products Marketing Company Limited(PPMC) and NPDC. As such facilities affected are all oil facilities. This cluster is in the vicinity of the 28-inch Trans-Forcados Pipeline, Escravos/Warri pipeline, with spills recorded around the settlements of Kolokologbene, Batan, Diebiri, Oteghele, and Tibigbene.

4 DISCUSSION

Perfunctory analysis of the events revealed that there are periods (years, months and days of the week) with more events than others. Thus, revealing that there is a temporal pattern to the incidents.

From the analysis, it is evident that incidents are relatively compact, much more than would have been expected if the events were to be occurring randomly over space. With the possibility that either the terrain or characteristics of the place influence the occurrence of oil spills and the occurrence of a spill at a location attracts more spills to nearby locations (first and second-order effects). Evidently, the presence of oil infrastructures could explain the clustering of the incidents.

Space-time trend showed that about a fifth of the locations have a discernible trend (uptrend or downtrend). Consequently, while the overall trend indicator may point to an increasing trend, there are subtle differences across the study area. The locations with increasing trend could represent areas with where there is an intersection of various enabling factors. While areas showing a decreasing trend could signify areas where the combination factors threatens such activities. Potentially, there is also the possibility that mitigation measures are beginning to take effect. These two areas (decreasing and increasing) as identified represents the understanding presented in the routine activity approach [21], optimal foraging concepts and rational choice theory within the framework of time constraints.

For the sporadic hot spots, the indication could be that a cat and mouse game is at play. At such locations, it is plausible to infer that since most of the spills are attributed to sabotage, the perpetrators are on the lookout for the absence of the enforcement agents. In the case of the consecutive hot spot, it seems plausible that while such places were not previously hot spots, something occurred which catalyse the intensification of oil spills in recent times. This clearly showed the relevance of time in spatial analysis incidents [11] since time can be a constraint to activities over space.

Hot spots were formed around both oil fields and pipelines while sabotage remained a dominant cause of spills in the region. Evidently, there is a high risk of oil business operations in the country. While this might be the case, the evidence suggests that the production system is resilient [29]. In a normal situation, the intensity and persistence of interdiction would have led to under-performance and possible collapse of the sector, but this is not the case. Therefore, indicating that interdiction or sabotage is not having a significant impact on the economic bottom line of the operators. Social actions in form sabotage or other forms of actions (leading to spills) against the oil multinationals are not having any desired economic impacts on them. Evidence of such was presented in the analyses of Yeeles and Akporiaye [29] which examined the impact of pipeline sabotage and theft on the Nigerian oil economy. Clearly the effect is more in the social and environmental sphere as presented by several authors (e.g. Ugor [7], Ayanlade and Proske [30], Pegg and Zabbey [31], Zhang, Matchinski [32], Anifowose, Lawler [33]). Since the impact is not fully felt by the operators, thus, there is a need for regulators to step up to stem the growth. The results of this study points to the need for such action and where such measure might commence.

5 CONCLUSION

There is evidence which shows that the pattern of incidents of oil spills in the region under investigation over the selected period is not random. There are many places experiencing increasing trends in spills while few places are experiencing decreasing trend in occurrence.

Incidents appeared widespread, however, from the analyses it could be concluded that they are quite compact. Thus, indicating the spatial autocorrelation between the oil spill incidents and certain characteristics of the locations.

Space-time trends were found, and they point to locations where there are space-time pattern especially hot spots for oil spills. Potentially, these could represent places where a combination of factors coincides to make the location more vulnerable to spills. Moreover, the creeks of Bayelsa and northern LGA of Rivers State represent some of the most important areas for oil spills over the period examined. The results identified statistically significant space-time pattern of incidents which could inform mitigation measures and facilitate the implementation of adequate risk management and contingency planning.

From the foregoing, we recommend the development of a decision support system which can dynamically examine the space-time trend and pattern of oil spills in Nigeria, to support the monitoring and enforcement operations of the relevant authorities. This is of great importance in the management of oil spills – proactive monitoring and crime prevention activity design and most importantly preventing or limiting environmental damages. All these are pertinent in working towards the achievement of SDG 13, 12 and 14 in this part of the country.

ACKNOWLEDGEMENTS

Our sincere appreciation goes to the National Oil Spill Detection and Response Agency (NOSDRA) for proving the data for this dataset and their support during the data cleaning process.

REFERENCES

1. Lawal, O. and C.U. Oyegun, *Geographic information systems-based expert system modelling for shoreline sensitivity to oil spill disaster in Rivers State, Nigeria.* Jàmbá: Journal of Disaster Risk Studies, 2017. **9**(1): p. 1-8.
2. NBS, *Nigerian Gros Domestic Product Report: Q2 2018*, in *GDP Report*, Y. Kale, Editor 2018, National Bureau of Statistics: Abuja. p. 89.
3. Jike, V.T., *Environmental Degradation, Social Disequilibrium, and the Dilemma of Sustainable Development in the Niger-Delta of Nigeria.* Journal of Black Studies, 2004. **34**(5): p. 686-701.
4. Opukri, C.O. and I.S. Ibaba, *Oil induced environmental degradation and internal population displacement in the Nigeria's Niger Delta'.* Journal of Sustainable Development in Africa, 2008. **10**(1): p. 173-193.
5. Anikpo, M., et al., *Gas Flaring in the Niger Delta*, 2013, National Coalition on Gas Flaring and Oil Spills in the Niger Delta: Port Harcourt. p. 47.
6. Attah, T. *Oil theft and artisanal (illegal) refining in Nigeria–scale, impacts and the need for a multi-dimensional response*. in *Chatham House–Gulf of Guinea Security Conference*. 2012. London: Chatham House.
7. Ugor, P.U., *Survival strategies and citizenship claims: youth and the underground oil economy in post-amnesty Niger Delta.* Africa, 2013. **83**(2): p. 270-292.
8. Lawal, O., *Space-time pattern and trend of armed conflicts in Nigeria: 1999 – 2015.* Port Harcourt Journal of Social Sciences, 2018. **8**(1): p. 49-67.
9. Allen, B., R.M. Bourke, and J. Gibson, *Poor rural places in Papua New Guinea.* Asia Pacific Viewpoint, 2005. **46**(2): p. 201-217.
10. Sachs, J.D., *Institutions don't rule: direct effects of geography on per capita income*, 2003, National Bureau of Economic Research.
11. Hägerstraand, T., *What about People in Regional Science.* Papers in Regional Science, 1970. **24**(1): p. 7-24.
12. Besag, J. and J. Newell, *The Detection of Clusters in Rare Diseases.* Journal of the Royal Statistical Society. Series A (Statistics in Society), 1991. **154**(1): p. 143-155.
13. Knox, E.G. and M.S. Bartlett, *The Detection of Space-Time Interactions.* Journal of the Royal Statistical Society. Series C (Applied Statistics), 1964. **13**(1): p. 25-30.
14. Kulldorff, M. and N. Nagarwalla, *Spatial disease clusters: detection and inference.* Statistics in medicine, 1995. **14**(8): p. 799-810.
15. Mantel, N. and J.C. Bailar, *A Class of Permutational and Multinomial Tests Arising in Epidemiological Research.* Biometrics, 1970. **26**(4): p. 687-700.
16. Glatman-Freedman, A., et al., *Near real-time space-time cluster analysis for detection of enteric disease outbreaks in a community setting.* Journal of Infection, 2016. **73**(2): p. 99-106.
17. Iftimi, A., et al., *Space–time airborne disease mapping applied to detect specific behaviour of varicella in Valencia, Spain.* Spatial and Spatio-temporal Epidemiology, 2015. **14–15**: p. 33-44.
18. Ceccato, V. and A.C. Uittenbogaard, *Space–Time Dynamics of Crime in Transport Nodes.* Annals of the Association of American Geographers, 2014. **104**(1): p. 131-150.
19. Wooditch, A. and D. Weisburd, *Using Space–Time Analysis to Evaluate Criminal Justice Programs: An Application to Stop-Question-Frisk Practices.* Journal of Quantitative Criminology, 2016. **32**(2): p. 191-213.
20. Townsley, M. and A. Oliveira, *Space-time dynamics of maritime piracy.* Security Journal, 2015. **28**(3): p. 217-229.
21. Cohen, L.E. and M. Felson, *Social Change and Crime Rate Trends: A Routine Activity Approach.* American Sociological Review, 1979. **44**(4): p. 588-608.
22. IBM, *IBM SPSS Statistics*, 2015, IBM Corporation: Armonk, New York.
23. ESRI. *Emerging Hot Spot Analysis*. 2016 [cited 2016 December, 15]; Available from: http://pro.arcgis.com/en/pro-app/tool-reference/space-time-pattern-mining/emerginghotspots.htm.
24. ESRI, *ArcGIS Desktop*, in *Release 10.7*2019, Environmental Systems Research Institute: Redlands, CA.
25. Kendall, M.G. and J.D. Gibbons, *Rank correlation methods*. 5th ed. 1990, London , UK: Edward Arnold . Oxford University Press
26. Mann, H.B., *Nonparametric tests against trend.* Econometrica: Journal of the Econometric Society, 1945. **13**(3): p. 245-259.
27. Getis, A. and J.K. Ord, *The Analysis of Spatial Association by Use of Distance Statistics.* Geographical Analysis, 1992. **24**(3): p. 189-206.
28. ESRI. *How Emerging Hot Spot Analysis works*. 2016 [cited 2016 December, 15]; Available from: http://pro.arcgis.com/en/pro-app/tool-reference/space-time-pattern-mining/learnmoreemerging.htm#GUID-09587AFC-F5EC-4AEB-BE8F-0E0A26AB9230.
29. Yeeles, A. and A. Akporiaye, *Risk and resilience in the Nigerian oil sector: The economic effects of pipeline sabotage and theft.* Energy Policy, 2016. **88**: p. 187-196.
30. Ayanlade, A. and U. Proske, *Assessing wetland degradation and loss of ecosystem services in the Niger Delta, Nigeria.* Marine and Freshwater Research, 2016. **67**(6): p. 828-836.
31. Pegg, S. and N. Zabbey, *Oil and water: the Bodo spills and the destruction of traditional livelihood structures in*

the Niger Delta. Community Development Journal, 2013. **48**(3): p. 391-405.

32. Zhang, B., et al., *Marine Oil Spills—Oil Pollution, Sources and Effects*, in *World Seas: an Environmental Evaluation*. 2019, Elsevier. p. 391-406.

33. Anifowose, B., et al., *Attacks on oil transport pipelines in Nigeria: A quantitative exploration and possible explanation of observed patterns.* Applied Geography, 2012. **32**(2): p. 636-651.