Spatial Analysis along a Network: Human and Environmental Exposure to Pipeline Hydrocarbon Pollution in the Niger Delta

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Summary

The prevalence of oil spills in the Niger Delta has led to severe environmental degradation and has had a range of impacts on the human population. Due to the uncertainty on the scale and extent, we applied spatial statistics and advanced specialised spatial analysis along a pipeline using a novel spills database. The analysis revealed 4 hotspots areas. Broad leaved trees, mangroves and arable land proved to be the most affected land cover types, and approximately 25% of the total population were found to live within high oil spill intensity area.

KEY WORDS: Pipelines, Sabotage, Oil Spills, Exposure.

1. Introduction

Oil and gas exploration activities take place in the Niger Delta. Pipelines are key infrastructures in ensuring the efficiency of production and distribution of petrochemical products, and also pivotal to economic growth (Anifowose et al. 2012). The petroleum industry over the years has been faced with the problem of oil spills; primarily through the sabotage of oil pipelines. Acts of sabotage is usually driven either by criminal intent to accrue wealth or political disaffection (Nwilo & Badejo 2005). Over the years sabotage and other factors such as operational accidents and aging infrastructure has led to a high number of spills. Between 1970-2006 over 1 billion barrels of oil have been spilled (Aroh et al. 2010), with severe health and environmental consequences.

Although the subject of oil spills in the Niger Delta has been previously studied, the extent of human and environmental exposure is not well known. This paper aims to identify hotspots from a database of oil spills (2007-2015) and investigate the extent of human and environmental exposure.

2. Methods

The study area is the Niger Delta, located in southern Nigeria. Data used include pipeline data sourced from Shell Petroleum Development Company, Nigeria; and spills data from the National Oil Spill Detection and Response Agency. In addition, landcover data from ESA's Global Climate Change Initiative was used (ESA, 2016). Population data used in estimating population exposure was sourced from Centre for International Earth Science Information Network Colombia University, New York. The gridded world population data was available at 1km^2 spatial resolution (CIESIN, 2016), and was released with the latest version GPWv4 and validated by UN population data.

2.1. Detecting Hydrocarbon Pollution Hotspots Along Pipelines

To determine oil spills hotspots along a pipeline network, Spatial Analysis along Network (SANET) was used. This specialist software for network-based events was developed in Japan. The toolbox was used in ArcGIS 10.4, however a stand alone version Beta1.0 is also available (Okabe 2015). SANET has previously been used to analyse road network incidents (Benedek et al. 2016). Here we apply the model to estimate hydrocarbon hotspots along pipeline network. Rather than using other hotspot

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detection method that uses euclidean distances (Mahboubi et al. 2015), SANET uses a function given by (Okabe & Sugihara 2012) shown in Equation 1.

$$k_y(x) = \begin{cases} k(x) & for -h \leq x \leq 2d - h \\ k(x) - \frac{2-q}{q} k(2d - x), & for\ 2d - h \leq x \leq d \\ \frac{2}{n} k(x) & for\ f \leq x \leq h \end{cases} \quad (1)$$

Given $k(x)$ is the kernel function, x is a point on the network (spill point), y is the midpoint of the kernel function, q is the degree of the node, h is the bandwidth in metres and d is the shortest distance from y to x in meters. The density (spill intensity) at a particular point of interest is computed using the formula:

$$D(O) = \int_{-h}^{2d-h} k(-y)dy + \int_{2d-h}^{d} \left[k(-y) - \left(\frac{2-q}{q}\right) k(-2d + y)\right] dy + \int_{d}^{h} (q-1)\frac{2}{q}\, k(-y)dy \quad (2)$$

2.2 Environmental and Population Exposure to Hydrocarbons

To determine environmental exposure to oil spills, a buffer of 2.5km which is the maximum pipeline impact radius (Shittu 2014) was created around each of the 5809 oil spill points. A python script was written and implemented to compute the different landcover type within each buffer and the areas summed to determine the extent of direct exposure by landcover types. To determine population exposure to oil spills, the pipeline spill intensity results produced by SANET were classified into low, medium and high spill categories. A 2.5km buffer was created for each classified segment and the tabulate area tool was applied to the population raster to estimate population within 2.5km of low, medium and high intensity section of the pipeline.

3. Results

3.1 Pipeline Hotspots

The application of SANET revealed several hotspots of hydrocarbon pollution. Figure 1 indicates almost all the hotspots are in the core Niger Delta states of Bayelsa, Delta, and Rivers. In particular 4 areas have been identified with high prevalence of oil spills: Ogbaebge (A), Gokana (B), Southern Ijaw (C) and Ekeremor (D). Unsurprisingly, of the 4 identified areas 3 including Gokana, Southern Ijaw and Ekeremor are remote coastal locations, whilst the fourth area Obgabegbe has a considerable number of leased oil fields. 220km (8.5%) of the pipeline network has been classified as medium or high spill intensity. This shows the prevalence of hydrocarbon pollution in the region.

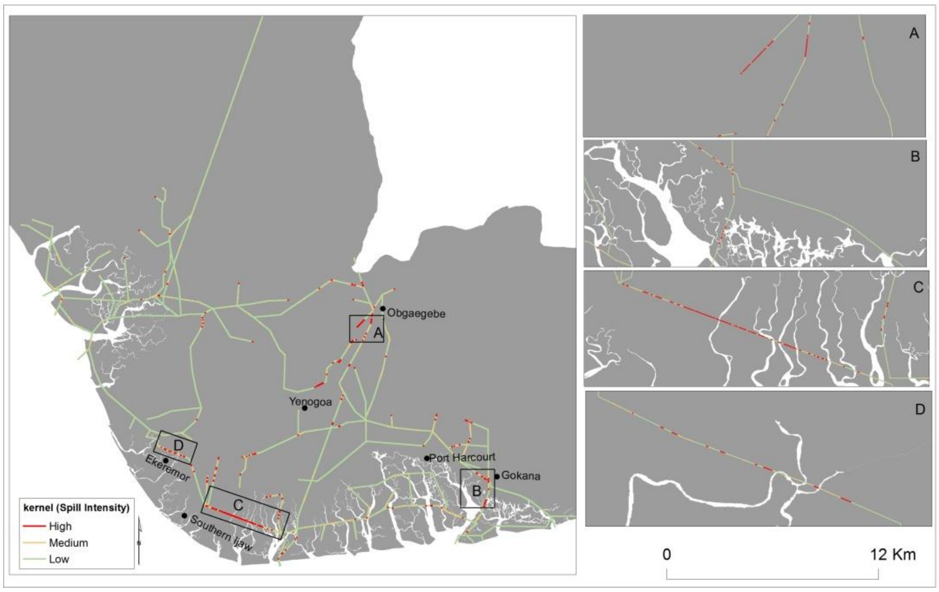

Figure 1 Oil spill hotspots in the Niger Delta determined by the "Network kernel Density Estimation method - NKDE" applied by the SANET tool.

3.2 Environmental Exposure

Our analysis shows a range of landcover types are adversely impacted by oil spills. Table 1 shows that 483km^2 of broad leaved tress are affected by oil spills. This represents 41% of total broad leaved cover in the buffer zone and makes it the most polluted landcover type. These trees belong to the tropical rainforest which are of high ecological importance. Mangroves are the second most affected landcover. These are known to be important spawning areas for fishes, and also support a wide range of biodiversity. Cropland and water bodies are also significantly affected. Destruction of cropland can contribute to food poverty and increase health risk from bioaccumulation. Oil, even in small quantities spreads faster in water thus polluting domestic supplies. An estimated 65km^2 of water bodies are affected by oil spills with substantial likely impacts on marine species, and on recreational activities such as swimming.

Table 1 Landcover Exposure to Hydrocarbon Pollution

Landcover	Area(km^2)	Percentage
Broadleaved Trees	483.0	41.50
Mangroves	309.9	26.56
Cropland	265.4	22.78
Water	65.7	5.64
Shrubs	21.5	1.85
Settlements	16.5	1.42
Grassland	3	0.25
Total	**1,164.90**	**100**

3.3 Human Exposure to Hydrocarbon Pollution

Our analysis also reveals a substantial number of people are exposed to oil spills. Table 2 shows population exposure according to classified pipeline spill intensity. Almost 1 million people live in close proximity to 62 km of pipeline exhibiting highest spills intensities. This group according to our analysis are most at risk. About third of the total population live in close proximity to the 158km of pipeline of medium spill intensity. Results also indicate a significant portion of the pipelines are low risk. This is because oil spills are more prevalent in hotspots; with over 80% occurring in 3 of the 9 Niger Delta states. Although there is a relative reduced exposure to oil spills in the low risk pipeline sections, research has shown that exposure to hydrocarbons even at minimal levels could be potentially harmful. This is because exposure has both long and short term effects. Skin contact, consumption, and breathing dangerous constituents has acute short term effects including respiratory complaints such as shortened breath and throat irritation, ocular (eye) symptoms such as soreness and redness. Neurological symptoms include dizziness, irritability, weakness and confusion. Longer term effects include respiratory effects including the chronic obstructive lung disease and carcinogenic effects such as leukaemia and cancers.

Table 2 Population exposure to oil spills by level of pipeline spill intensity

Spill Intensity	Length (km)	Population	Percentage
Low	2,365	2,173,919	47.7
Medium	158	1,484,340	32.5
High	62	903,509	19.8
Total	**2,585**	**4,561,768**	**100**

Figure 3 shows the spatial extent of exposure to oil spills. This has been derived from the total number of residents living within the pipeline impact radius and the volume of oil spills. The result is quite revealing as in some areas the dosage of oil per person is in excess of 500 litres. However, the average dosage per person is 23 litres, while 2 litres and 63 litres makes the 5th and 95th percentile of dosage. It also shows south western part of the Niger Delta as the most affected, with the exception of Ibeno a coastal town in the southeast.

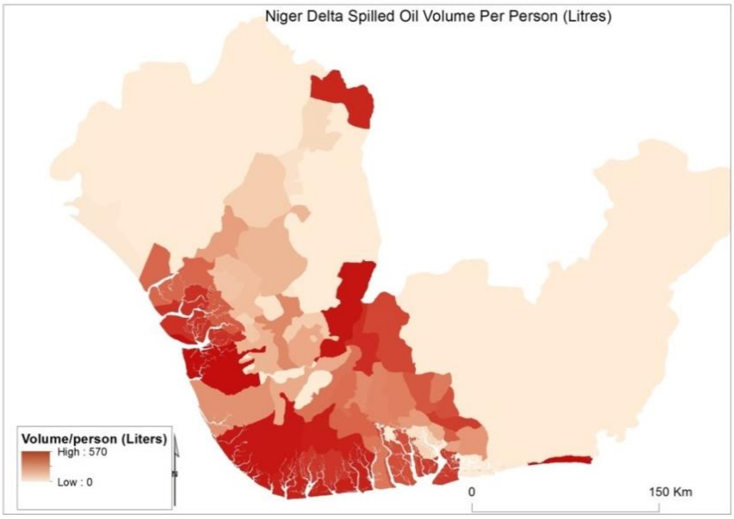

Figure 3 Oil spill exposure by spill volume to population within pipeline impact radius according to local government areas of the Niger Delta.

4. Conclusion

The notion that the Niger Delta is the oil spill capital of the world as suggested by (Duffield 2010) has been substantiated in this paper. Data on population, landcover, oil spills and pipeline from different sources were integrated then analysed using a novel spatial analysis along network tool. The nature and scale of oil spill exposure and attendant health implications in the Niger Delta were subsequently highlighted. The core Niger Delta states of Bayelsa, Delta and Rivers were identified as having the highest cumulative exposure to oil pollution. Since mangroves, broad leaved trees and cropland are the most affected landcover types, there are significant impacts upon ecological functions and food production that can lead to poor quality of life. There is the need to develop an integrated spatial framework to better detect the direct and indirect impacts of spills. This in turn may lead to more rapid spill management and effective remediation of impacted areas.

5. Biography

Christopher Obida is an early career researcher, and a second year PhD student at Lancaster University with research interest in geospatial data applications in solving environmental problems.

Duncan Whyatt is a Senior Lecturer in GIS at Lancaster University with research interests in both the natural and social sciences.

Alan Blackburn is a Senior Lecturer in remote sensing at Lancaster University with research interest in developing remote sensing and GIS techniques for environmental applications.

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